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FIELD MANUAL

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FUNDAMENTAL OF AIRFRAME MAINTENANCE

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HEADQUARTERS
DEPARTMENT OF THE ARMY
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CHAPTER 1

INTRODUCTION

1. Purpose

This manual provides maintenance personnel with the fundamentals pertaining to airframe maintenance. The information is designed as a training guide and basic reference manual for aircraft repairmen.

2. Scope

a. The information contained in this manual is presented as general information on aircraft structural repair for Department of Army aircraft and is not directed at specific aircraft. For more detailed information than that found in this manual, refer to the TM 55-1500 series manuals. For specific instructions on structural

repairs of a particular aircraft, refer to the applicable portion of the organizational and field maintenance manuals on the particular aircraft.

b. Users of this manual are encouraged to submit recommended changes or comments to improve the manual. Comments should be keyed to the specific page, paragraph, and line of the text in which the change is recommended. Reasons should be provided for each comment to insure understanding and complete evaluation. **Comments should be prepared on DA Form 2028 (Recommended Changes to Publications) and forwarded direct to the Commandant, US Army Transportation School, ATTN: ATSTC-TDL, Fort Eustis, Virginia 23604.**

CHAPTER 2

AIRCRAFT STRUCTURES

Section I. GENERAL

3. Early Aircraft Structures

a. In aviation's early days, wood and fabric, reinforced by metal accessories, were strong enough to withstand the vibrations and torsional stresses occurring in slow flying aircraft. Maintenance of the wooden parts had to be performed by highly skilled woodcraftsmen, and little metal repair was needed.

b. With the need for higher speeds, greater payloads, and the consequent development of more powerful engines, wood became unsatisfactory. Engineers and manufacturers realized that structural parts made from metal would have to replace wood, so they developed light but strong metal alloys. To these they applied structural forming and reinforcement methods to save more weight and provide the strength required for increased performance.

4. Present Day Aircraft Structures

a. The shift from wood to metal called for a corresponding change to train maintenance personnel from woodcraft to metalworking. Instead of having to know such details as the grain, strength, and weight of various woods, the repairman had to learn about the characteristics of sheet metals.

b. Application of these principles involves selecting the kind of metal for structural strength and streamlining, the style of rivet to use, and the type of patch that will retain correct contour; determining how much weight can be added and still be within safe limits; and choosing the methods of structural forming and reinforcement to use. With the development of newer, lighter, and stronger alloys, the airframe repairman must keep abreast of such developments, not only in maintenance, but in aviation generally.

Section II. PRINCIPAL STRUCTURAL UNITS

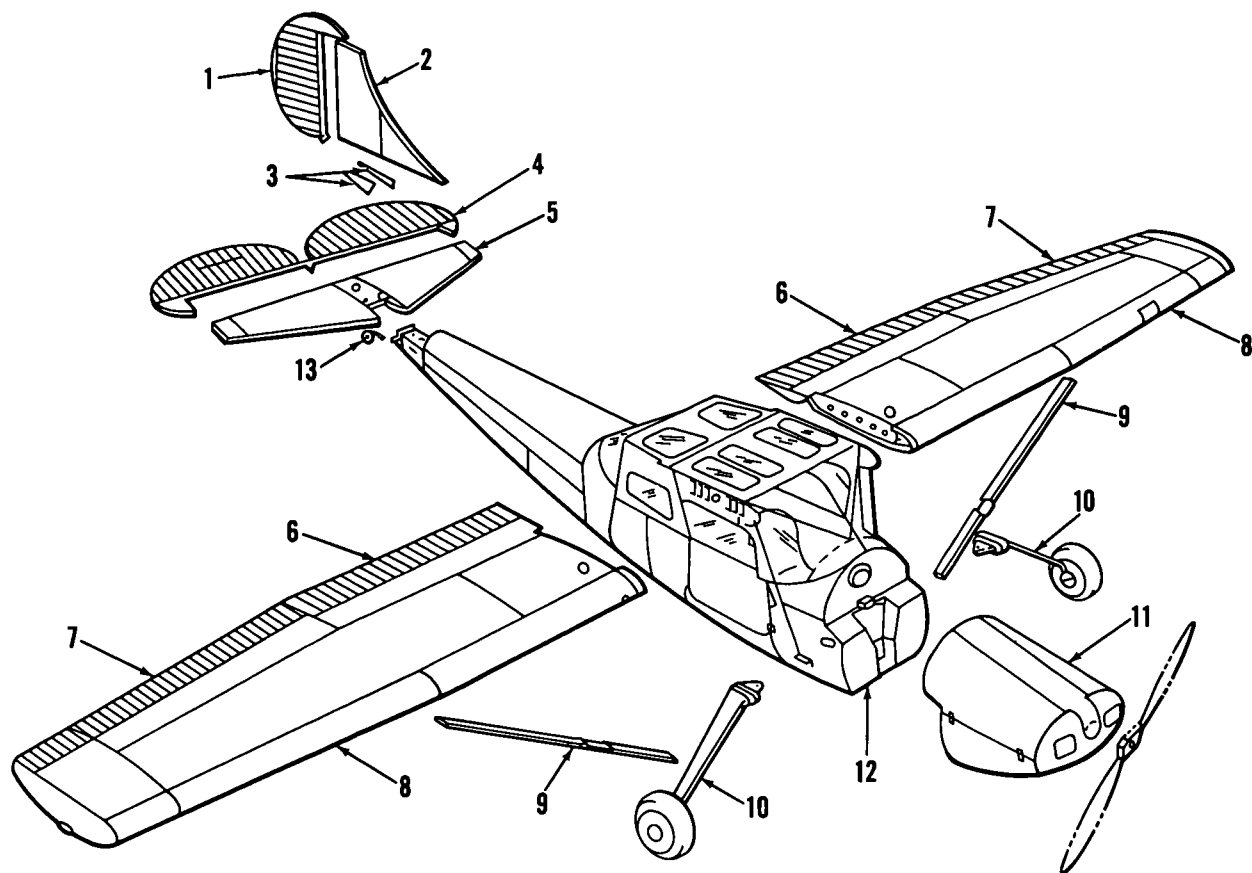
5. General

An aircraft is constructed of many parts which are either riveted, bolted, screwed, bonded, or welded together. Since these parts make up the structure of the aircraft, they are called structural members. Many of these members can be grouped into several units or assemblies. The principal airframe parts for airplanes and helicopters are shown in figures 1 and 2. The combined units are often called the aircraft structure, or the airframe, and the repair and maintenance of the structural members is called airframe maintenance or repair. A clear understanding of the location, construction, and purpose of the various structural units of the aircraft is necessary for an intelligent approach to the problems of airframe repair.

6. Principal Airframe Parts (Airplane)

a. *Fuselage.* The fuselage is the main struc-

tural unit of the airplane. Other structural units are directly or indirectly attached to the fuselage. From the standpoint of outline and general design, the fuselage of one type of airplane is much the same as any other. A variety of designs have been successfully tried for the many different requirements and the most satisfactory features are still incorporated in the latest airplanes. They vary principally in size and arrangement of the different compartments. On military single-engine airplanes, the fuselage houses the powerplant, the personnel, and the cargo. On most multiengine airplanes, the powerplants are housed in compartments called nacelles, which are built into the wings, or the powerplants are suspended in pods from the wings or fuselage. The detail of fuselage design varies with the manufacturer of the airplane and with the requirements of the service for which the airplane is intended.



1 Rudder
2 Vertical stabilizer and dorsal fin
3 Fairings
4 Elevator

5 Horizontal stabilizer
6 Flap
7 Aileron
8 Wing
9 Strut

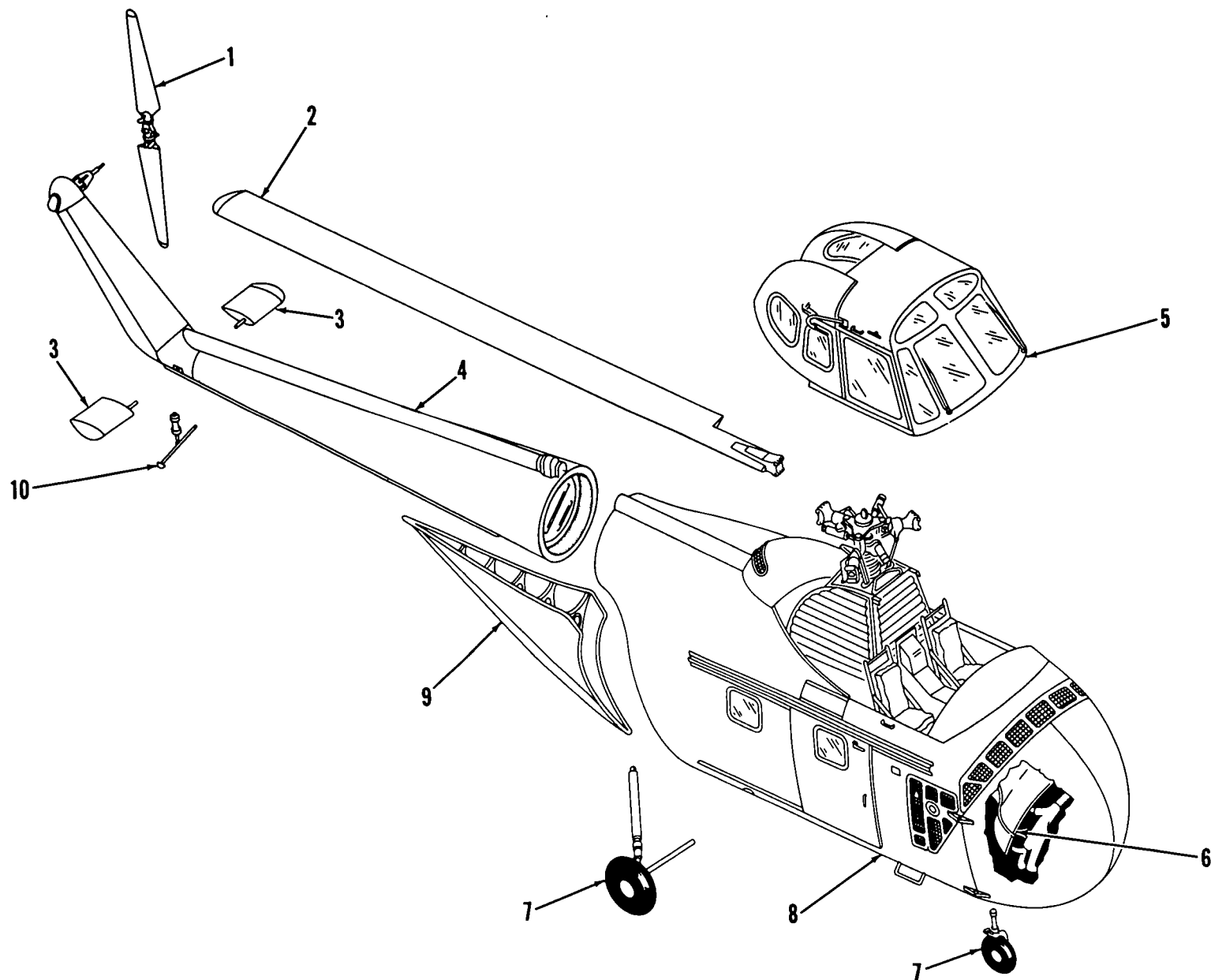
10 Main landing gear
11 Engine cowling
12 Fuselage
13 Tail gear

Figure 1. Principal airframe parts (airplane).

(1) *Construction.* The two basic types of fuselage construction are the truss and the monocoque.

(a) *Truss type.* The truss type construction, a rigid framework made up of members such as beams, struts, and bars, resists deformation by applied loads. The fabric-covered, truss-framed fuselage is built for low power rating, slow speeds, and light construction. The truss type is used in many of the smaller civilian airplanes and was formerly used in many Army airplanes. This type of construction is still being used in some helicopters. Examples of truss-type construction are shown in figure 3.

(b) *Monocoque type.* The monocoque-type construction is constructed like a shell in which the skin of the fuselage bears the primary stresses. The strength of construction required depends upon the power used, speed, maneuverability, and design. The full monocoque-type of construction is seldom used because the skin acts as the principal part of the airframe. Formers, frame assemblies, and bulkheads are used to provide shape but the skin carries the primary stresses (fig. 4). One of the big problems in monocoque construction, is maintaining enough



1 Tail rotor blade
2 Main rotor blade

3 Stabilizer
4 Tail cone section

5 Canopy
6 Powerplant compartment

7 Main landing gear
8 Cabin section

9 Fin
10 Tail skid

Figure 2. Principal airframe parts (helicopter).

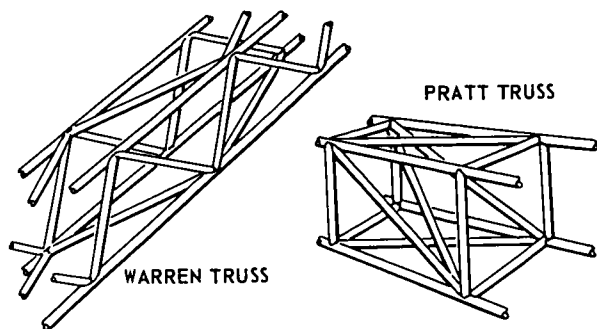


Figure 3. Truss-type construction.

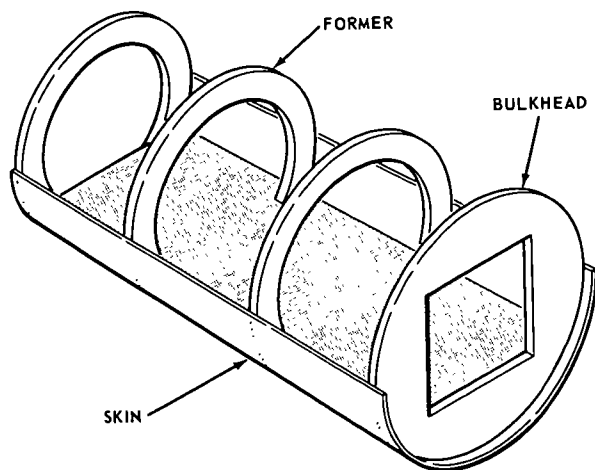


Figure 4. Monocoque-type construction.

strength, yet keeping the weight within allowable limits. To overcome the strength-weight problem of monocoque construction, two additional classes or modifications of monocoque construction were developed: Semimonocoque, and reinforced shell. These two classes are primarily used in construction of nearly all present day military airplanes. The semimonocoque-type, in addition to having vertical reinforcements, has the skin reinforced by longitudinal members. The reinforced shell has the skin reinforced by a complete framework of structural members. Examples of semimonocoque and reinforced shell types of construction are shown in figures 5 and 6.

(2) Structural members

(a) Bulkheads, frame assemblies, and formers serve the dual purpose of giving cross-sectional shape to the fuselage, and of adding rigidity and strength to the structure. The shape and size of these members vary considerably, depending on their function and position in the fuselage. Formers are the lightest and are used primarily for fillings or skin attachments between the larger members. Frame assemblies are the most numerous and outstanding members

in the fuselage, both from the standpoint of appearance and as strengthening devices. Whenever frame assemblies are used to separate one area from another, they become circular discs, reinforced, and equipped with doors or other means of access, and are called bulkheads.

(b) Channel members, hat sections, and built-up assemblies are inserted to provide additional strength. Station webs are built-up assemblies located at various points for the attachment of fittings or external parts, such as empennage surface fittings, engine mounts, wing attachments, and landing gears.

(c) Stringers and longerons are the main lengthwise members of the fuselage structures. In figure 6, note that the longeron is a fairly heavy member. Several of these usually run the whole length of the fuselage.

(d) The stringers are smaller and lighter and serve as fill-ins. They have some rigidity, but are chiefly used for giving shape and for attachment of the skin. Longerons are stronger and heavier than stringers. The longerons hold the bulkheads and formers, and these, in turn, hold the stringers. All of these joined together form a rigid fuselage framework.

b. *Nacelle*. Nacelles are streamlines structures used on multiengine aircraft primarily to house the engines. Here again the design varies, depending partly on the manufacturer and partly on the use for which the nacelle is intended. On twin-engine airplanes, the nacelles also house the main landing gear and related equipment. Whether the nacelle houses a piston-type reciprocating engine, a jet engine, landing gear, cargo, or personnel, the fundamentals of repair are essentially the same as for the fuselage. There must be sufficient strength, whether truss, monocoque, or semimonocoque; the weight must be kept to a minimum; and the exterior must be aerodynamically suited for the nacelle's place on the airplane. Airframe maintenance on the nacelle involves the skin, formers, bulkheads, rings, longerons, and so forth, as in the fuselage (fig. 7).

c. *Wings*. The wings of an airplane are surfaces designed to give lifting force when moved forward rapidly through the air. The particular wing design for any given airplane depends on a number of factors; such as, size, weight, use of the airplane, desired speed in flight and at landing, and desired rate of climb. The wings are designated as left and right, corresponding to the left and right hands of the pilot seated in the pilot's compartment. Features of the wing will cause variations in its design. The wingtip may be square, rounded, or even pointed. Both the leading edge and the trailing edge of the

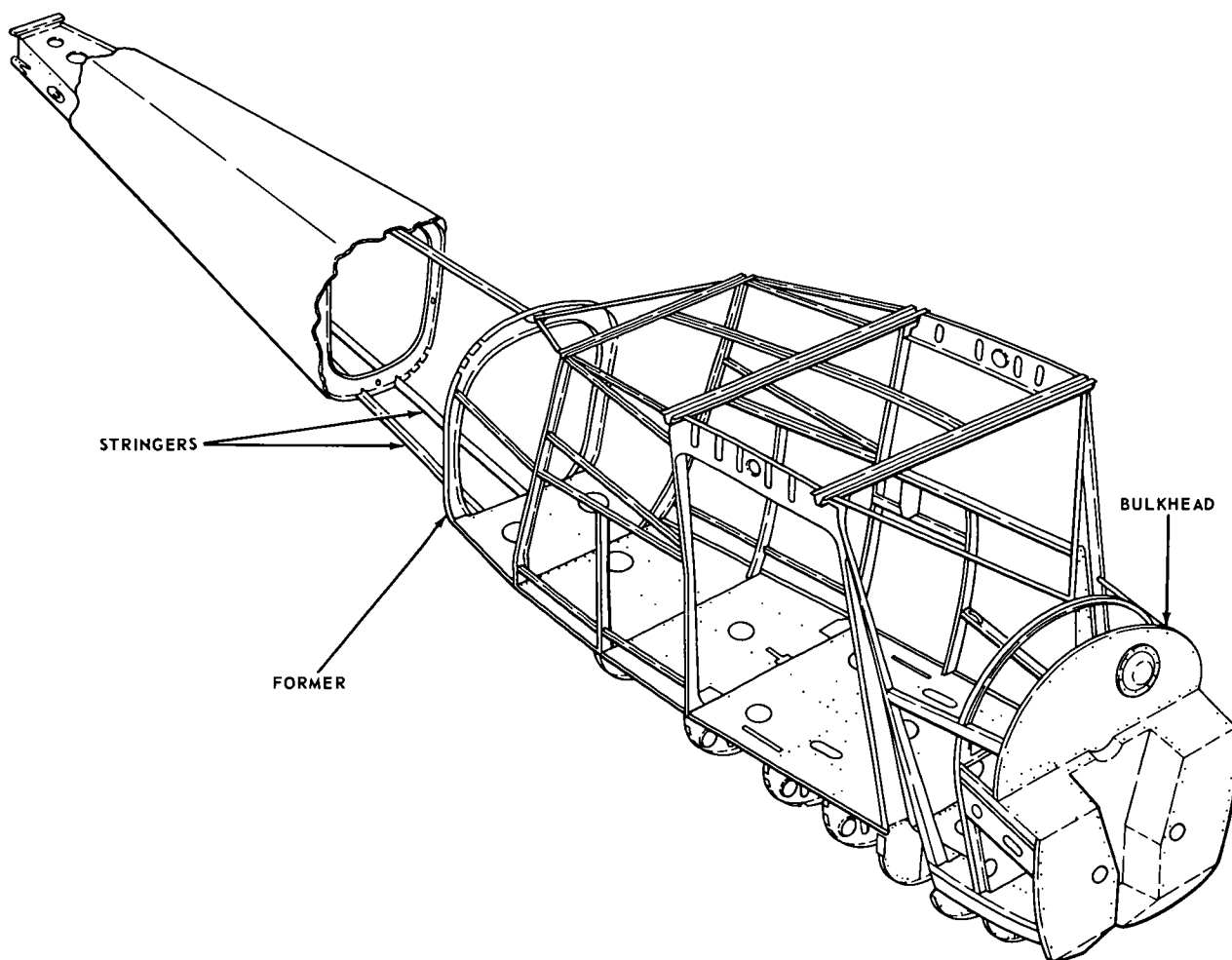


Figure 5. Semimonocoque-type construction.

wing may be straight or curved, or one edge may be straight and the other curved. In addition, one or both edges may be tapered so that the wing is narrower at the tip than at the root where it joins the fuselage. Numerous types of modern airplanes employ swept-back wings. The wings of military airplanes are usually of cantilever design; that is, they are built so that no external bracing is needed. With few exceptions, wings of this design are of the stressed skin type, which means that the skin is part of the wing structure and carries part of the wing stresses. In general, wing construction is based on one of three fundamental designs: Monospar, multispar, and box beam. Slight modifications of these basic designs may be adopted by various manufacturers.

(1) *Monospar wing.* The monospar wing incorporates only one main longitudinal member in its construction. Ribs or bulkheads sup-

ply the necessary contour or shape to the airfoil. Although the strict monospar-type wing is not common, this type of design, modified by the addition of false spars or light shear webs along the trailing edge as support for the control surfaces, is often used.

(2) *Multispar wing.* The multispar wing incorporates more than one main longitudinal member in its construction. To give the wing contour, ribs or bulkheads are often included. This type of construction, or some modification of it, is used in the lighter types of airplanes.

(3) *Box beam wing.* The box beam type of wing construction uses two main longitudinal members with connecting bulkheads to furnish additional strength and to give contour to the wing. A corrugated sheet may be placed between the bulkheads and the smooth outer skin so that the wing can better carry tension and compression loads. In some cases, heavy longitudinal stiffeners are substituted for the corrugated

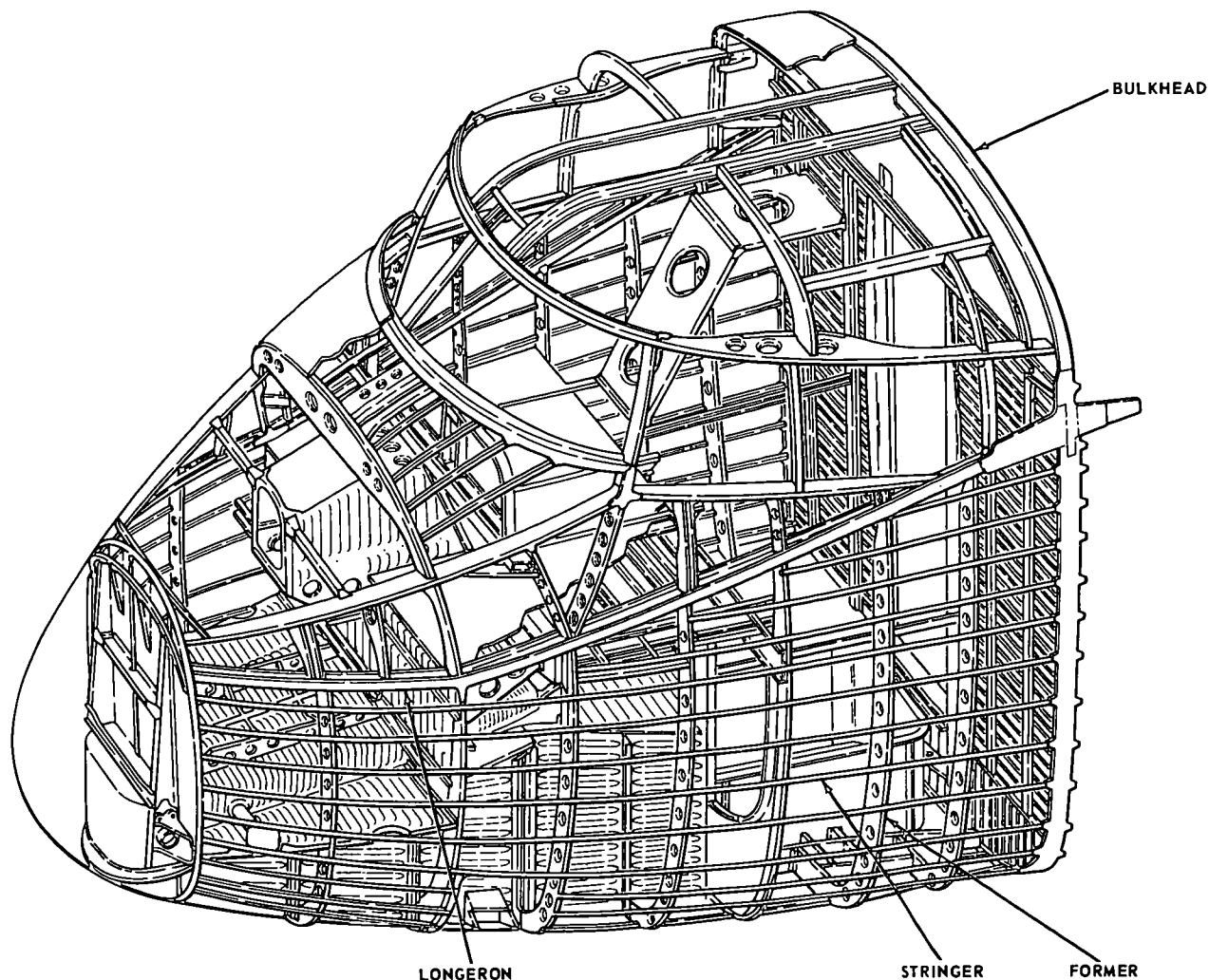


Figure 6. Reinforced shell-type construction.

sheets. A combination of corrugated sheets on the upper surface of the wing and stiffeners on the lower surface is sometimes used.

(4) *Internal construction.* The main structural components of a wing are the spars, the ribs or bulkheads, and the stringers or stiffeners, as shown in figure 8. These structural parts are riveted or welded together.

(a) *Spars and stiffeners.* Spars are the principal structural members of the wing. They correspond to the longerons of the fuselage. Spars run parallel to the lateral axis, or toward the tip of the wing, and are usually attached to the fuselage by wing fittings, plain beams, or part of a truss system. The I-beam type of construction for a spar consists of a web (the deep wall plate) and capstrips (which are extrusions or formed angles) A, figure 8. The web forms the principal depth portion of the spar. Capstrips are extrusions, formed angles, or milled sections to which the web is attached. These carry the loads caused by the wing bending,

and also provide a foundation for attaching the skin. Stiffeners give additional strength to the spar structure. Stiffeners may be beads pressed into the web, or extrusions or formed angles riveted to the web either vertically or diagonally.

(b) *Ribs.* Ribs are the crosspieces that make up the framework of a wing. They run from the leading edge toward the trailing edge (front to rear) of the wing. The ribs give the wing its contour or shape and transmit the load from the skin to the spars. Ribs are also used in ailerons, elevators, fins, and stabilizers. There are three general types of rib construction, as shown in figure 9. The reinforced rib and the truss rib are both relatively heavy as compared to the former rib, and are located only at points where the greatest stresses are imposed. Former ribs are located at frequent intervals throughout the wing. The reinforced rib is similar in construction to that of spars, consisting of upper and lower capstrips joined

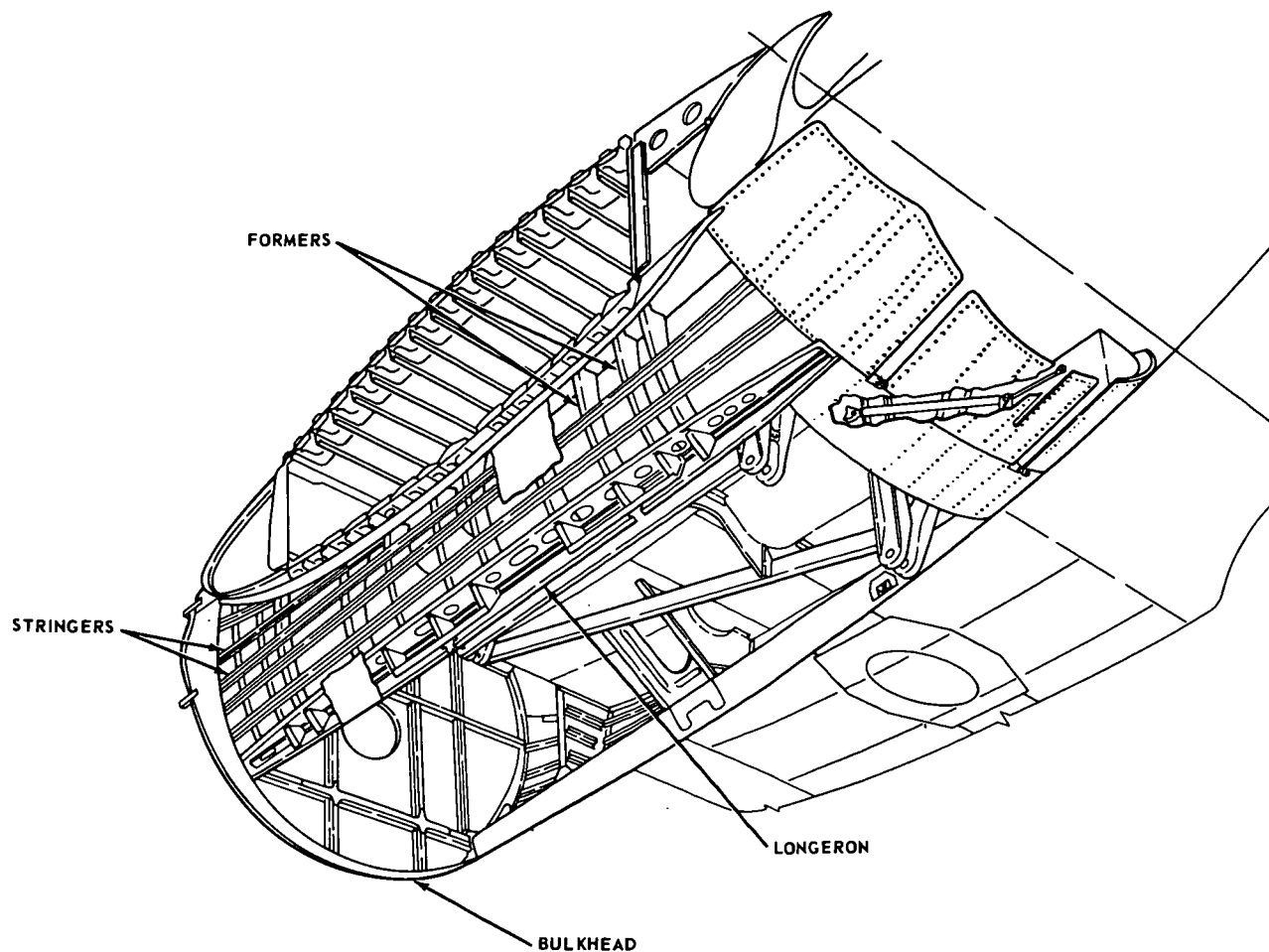


Figure 7. Nacelle construction.

by a web plate. The web is reinforced between the capstrips by vertical and diagonal angles. The reinforced rib is much more widely used than the truss rib. The truss rib consists of capstrips reinforced solely by vertical and diagonal cross members. Former ribs are made of formed sheet metal and are very light in weight. The bent-up portion of a former rib is referred to as the flange, and the vertical portion is called the web. The web is generally constructed with lightening holes, with beads formed between the holes. The lightening holes lessen the weight of the rib without decreasing the strength. Rigidity of lightening hole areas is accomplished by flanging the edges of the lightening holes. The beads stiffen the web portion of the rib.

d. Empennage. The empennage is simply the tail section of the airplane. It includes the aft end of the fuselage or booms, the rudder or rudders, elevators, stabilizers and trim tabs (fig. 10). The stabilizing units of an airplane consist of vertical and horizontal surfaces located on the rear portion of the fuselage. They are parts of the empennage or tail assembly. The

fixed vertical surface is called the vertical stabilizer, or fin, and the fixed horizontal surface is referred to as the horizontal stabilizer. The vertical stabilizer, or fin, serves to maintain directional stability of the airplane in flight about its vertical axis. On single engine, propeller driven airplanes, the vertical fin is sometimes offset in relation to the centerline of the fuselage to furnish directional stability by compensating for the torque or twist caused by the engine and propeller. The vertical fin is also the base or anchorage for attaching the rudder. Stability about the lateral axis of the airplane is given by the horizontal stabilizer, which serves also as a base or anchorage for attaching the elevators. As with the wings, there are many variations to be found in the size, shape, and placement relative to the fuselage, as well as in the number of component parts comprising the empennage. Construction features are in many respects identical with those of the wings. They are usually of all-metal construction and of the cantilever design. Monospar and multispar construction are both commonly used. Ribs develop

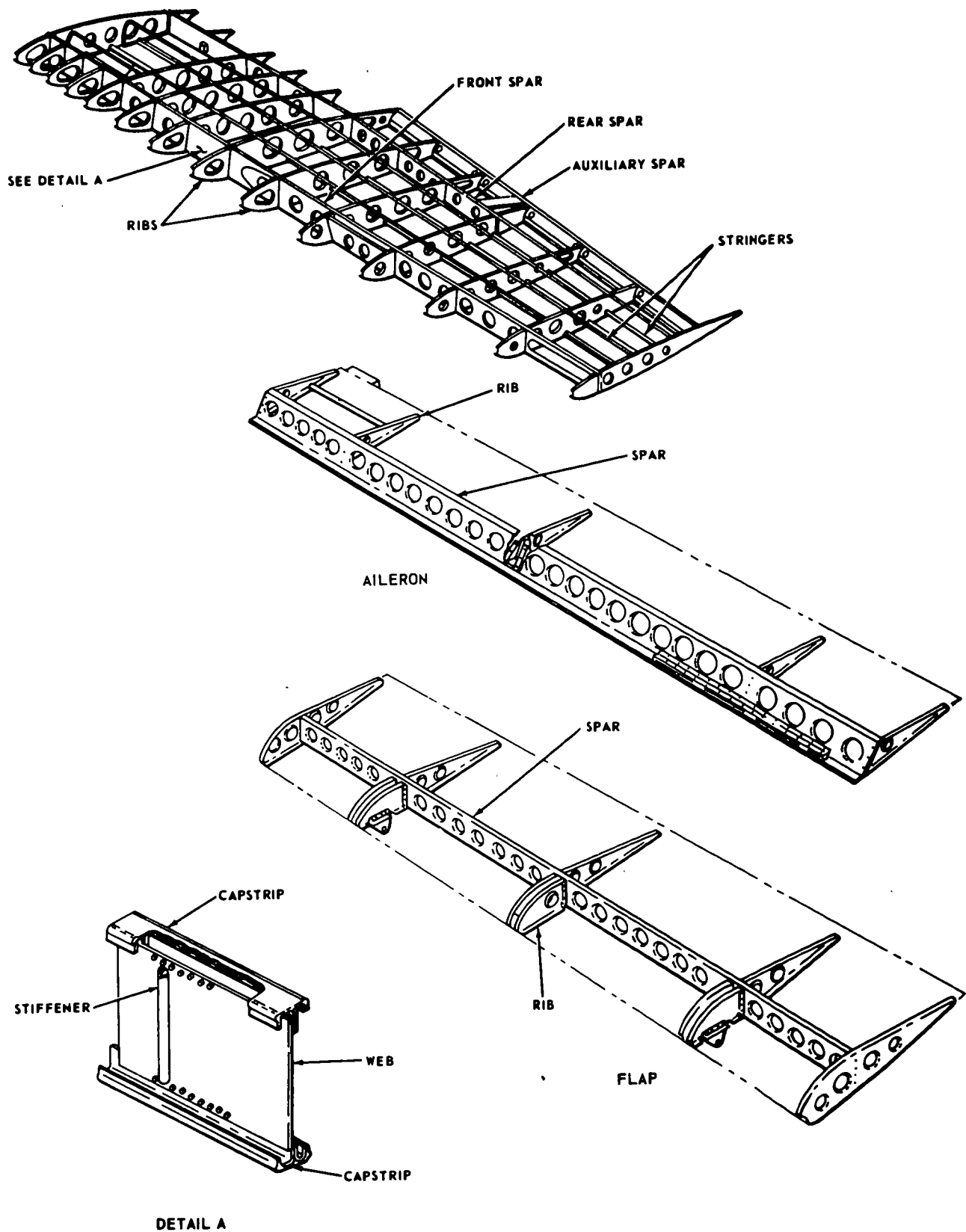
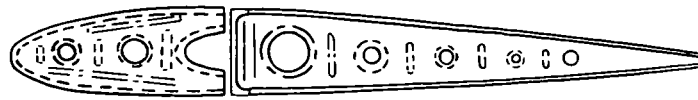
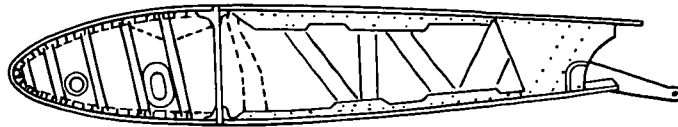


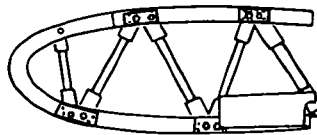
Figure 8. Wing Construction.



FORMED RIB



REINFORCED RIB



TRUSS RIB

Figure 9. Types of ribs.

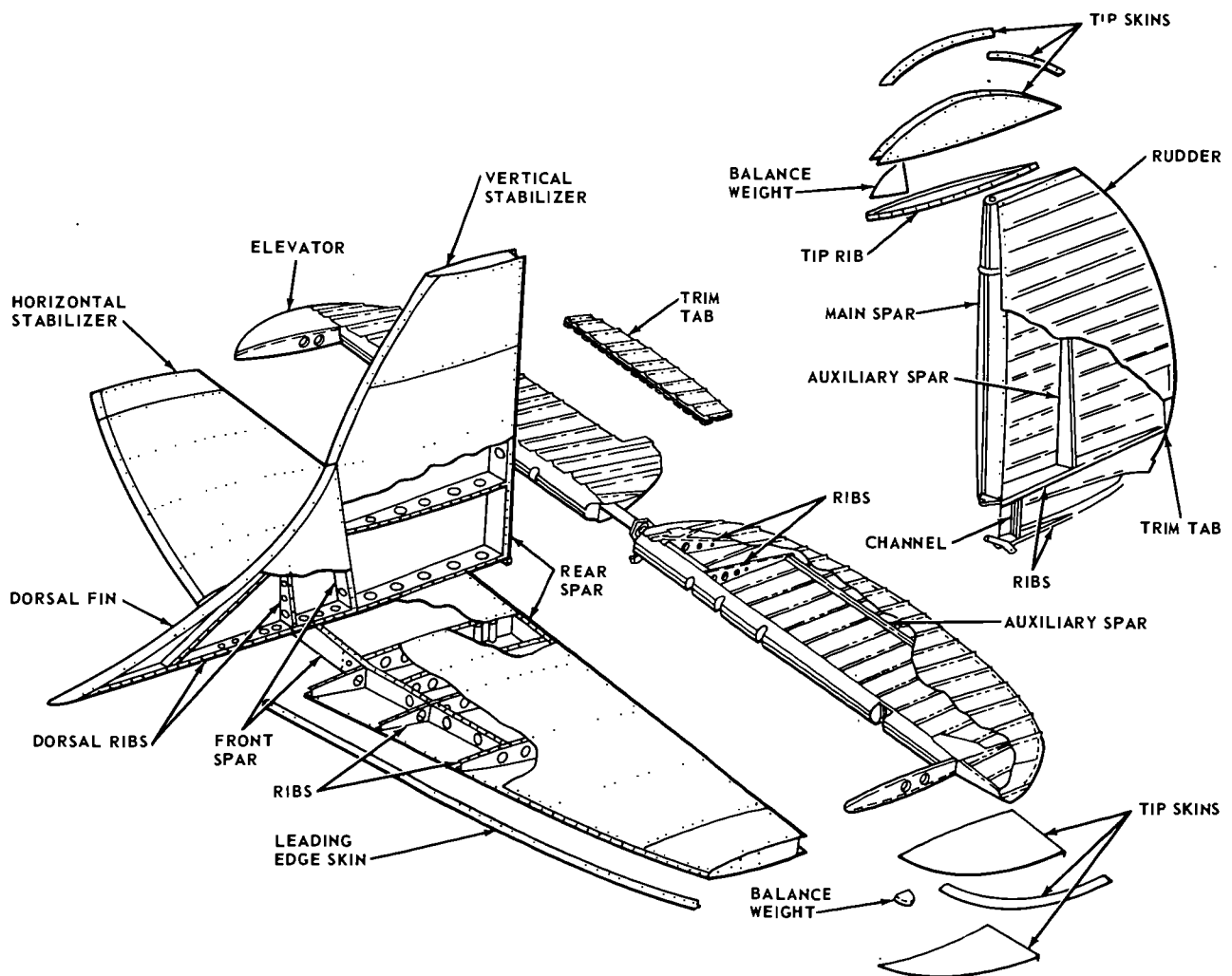


Figure 10. Empennage construction.

the cross-sectional shape. Fairing is used to streamline the angles formed between these surfaces and the fuselage.

7. Principal Airframe Parts (Helicopter)

a. Cabin and Tail Cone Sections. A typical single-rotor helicopter is composed of two major sections, the cabin and tail cone. The cabin section contains passenger or cargo compartments which supply space for the crew, passengers, cargo, fuel and oil tanks, controls, and powerplant except in multiengine helicopters in which the powerplants are mounted internally or externally in separate engine nacelles. The tail cone section and landing gear are attached to the cabin section in such a manner that they can be inspected, removed, repaired, and replaced when necessary. The cabin is strong enough at points of attachment to withstand forces involved in flying and landing. The size and arrangement of cabin compartments vary with different types of helicopters. The tail cone section attaches to the cabin and supports the tail rotor, tail rotor drive shafts, and stabilizer. The same type of construction employed in the fuselage of airplanes is utilized in the construction of the cabin and tail cone sections of helicopters.

b. Stabilizer. The stabilizer is secured to the pylon of the tail cone section to increase longitudinal stability of the helicopter during forward flight. The same type of construction em-

ployed in the stabilizer of airplanes is utilized in helicopters (fig. 11).

c. Main and Tail Rotor Blades. The main and tail rotor blades are rotary airfoil surfaces. The main rotor blades provide the necessary lift for flight of the helicopter. Torque created by rotation of the main rotor blades is compensated for by the tail rotor blades. Although some of the earlier helicopters utilized blades constructed of wood, the blades are primarily of all-metal construction. A typical rotor blade contains an extruded leading edge spar, trailing edge, balance plates, root and tip fairings, and a cuff attachment point. The leading edge spar is the main supporting member. The trailing edge consists of ribs and pockets attached to the leading edge spar with adhesive bonding. Typical construction features of main and tail rotor blades are shown in figures 12 and 13.

8. Flight Control Surfaces

On airplanes, flight control surfaces are hinged or moveable surfaces which may be divided into three groups referred to as primary, secondary, and auxiliary. The primary group, consisting of ailerons, elevators, and rudder, is used to control the airplane about all three axes, the lateral, the longitudinal, and the vertical, as shown in figure 14. The ailerons are attached to the trailing edge of the wing sections of both the right and left wings of the airplane. The elevators are attached to the trailing edge portion of the

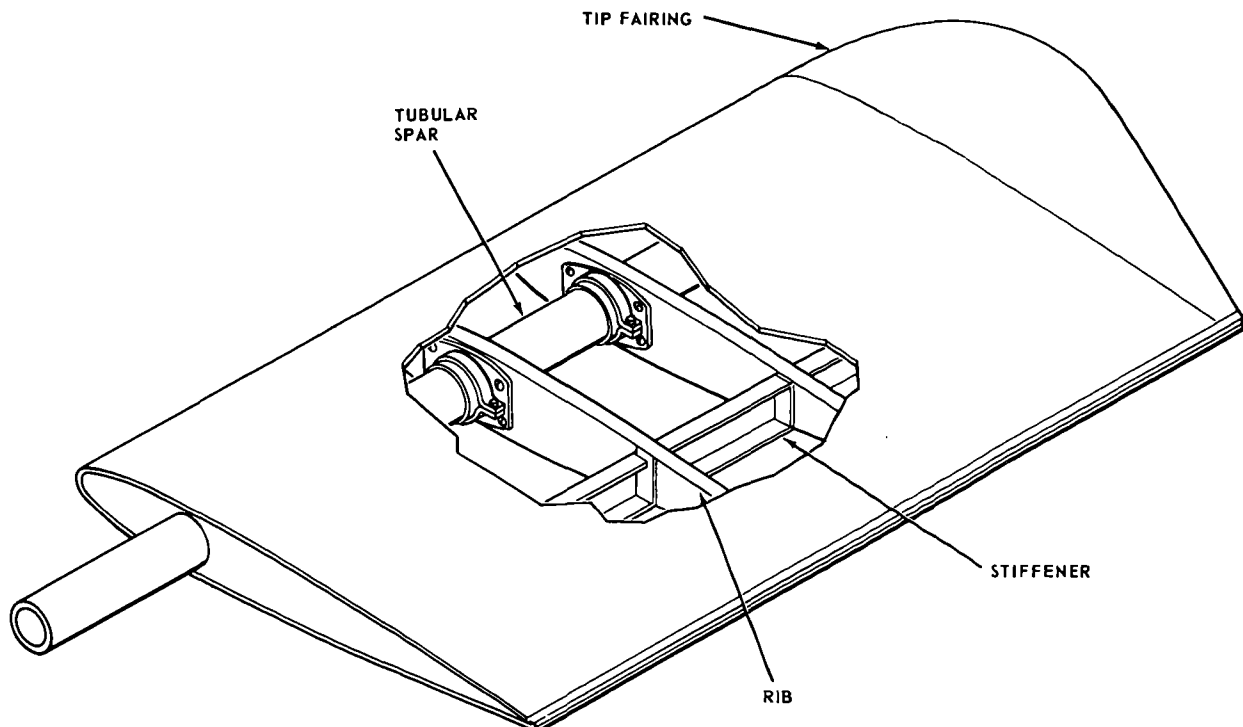


Figure 11. Stabilizer construction.

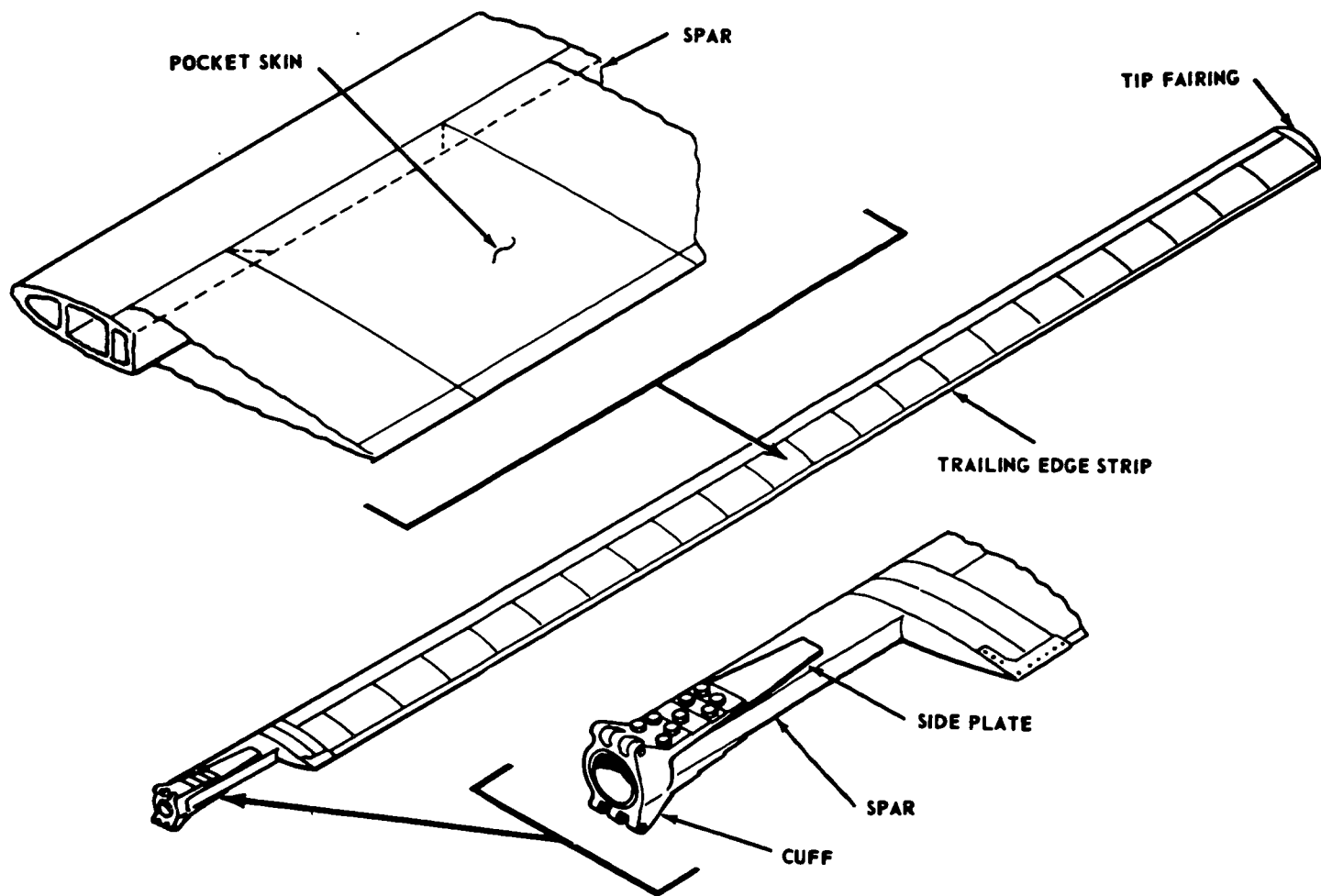


Figure 12. Main rotor blade construction.

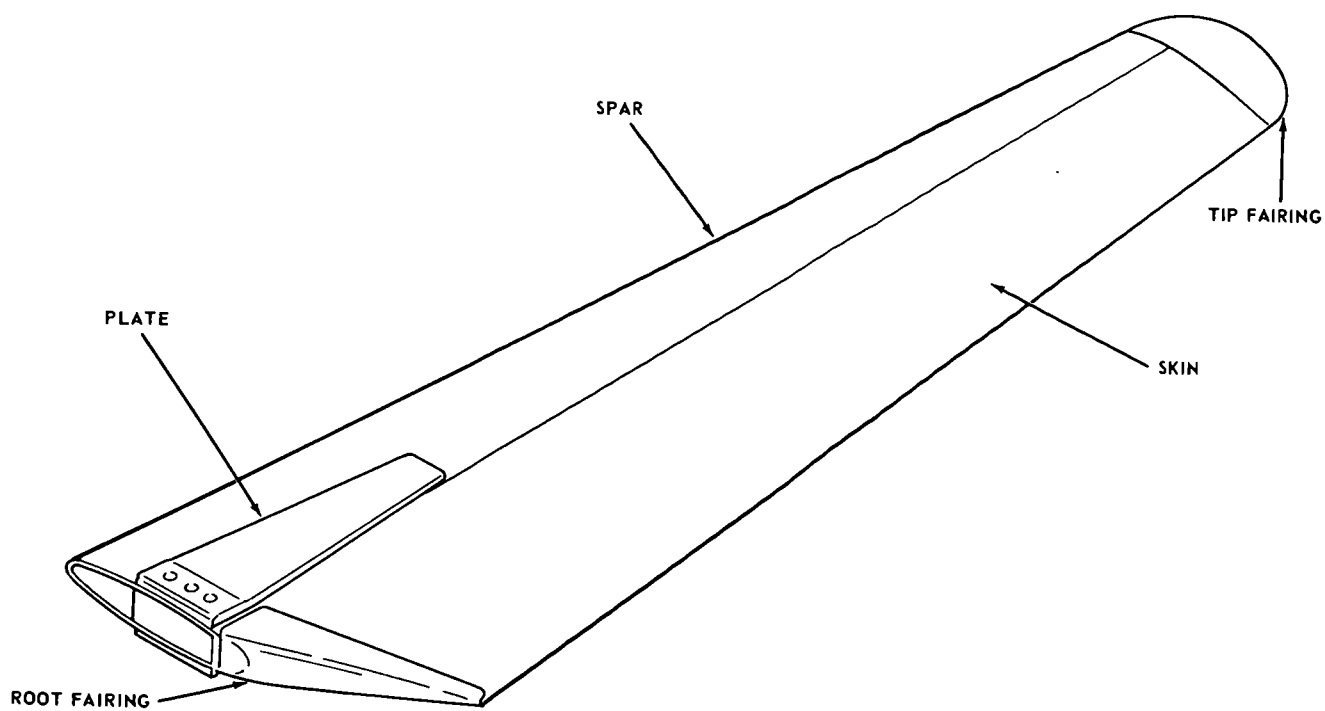


Figure 13. Tail rotor blade construction.

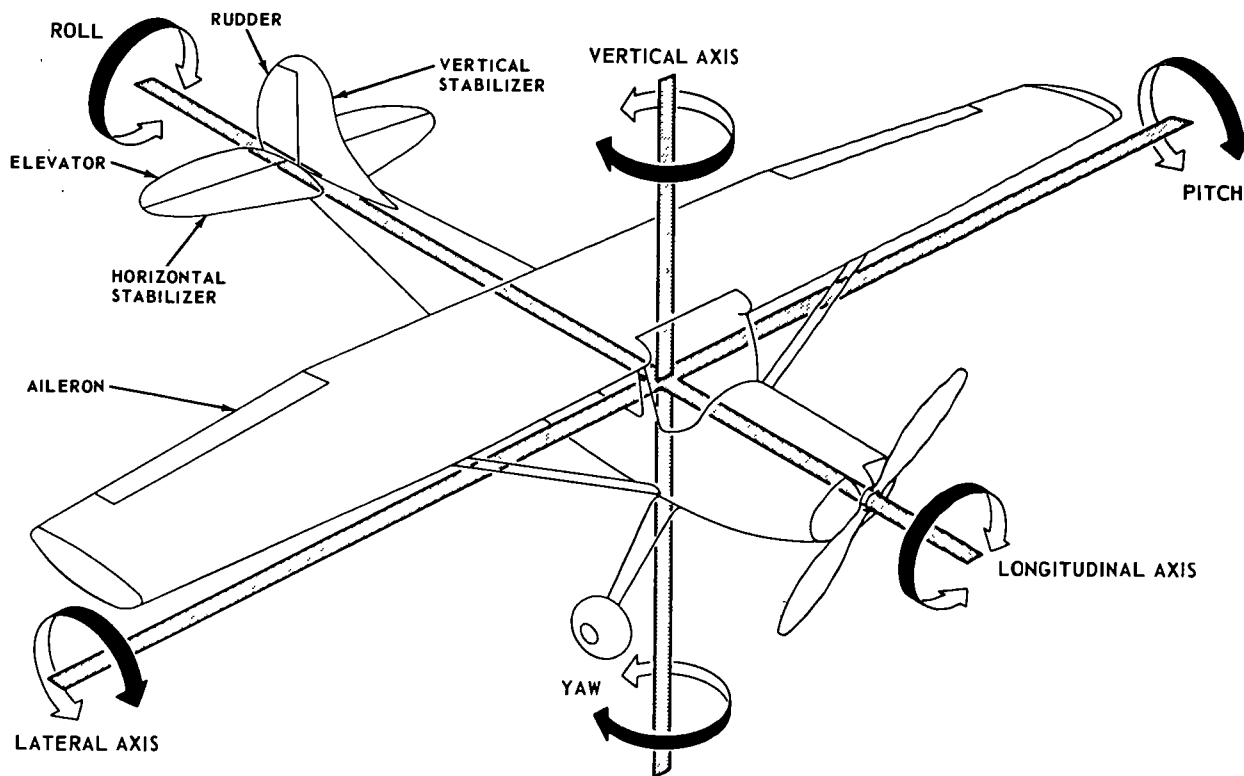


Figure 14. Axes and fundamental motions.

horizontal stabilizer and the rudder is attached to the trailing edge portion of the vertical stabilizer. The secondary group of control surfaces is composed of trim tabs and spring tabs; their purpose being to trim the airplane in flight or reduce the force required to actuate the primary control surfaces. Trim tabs and spring tabs are small airfoils recessed into the trailing edges of the primary control surfaces. The third, or auxiliary group, includes wing flaps, speed brakes, slats, and spoilers; their purpose being to reduce landing speed or shorten the length of landing roll and to change the speed of the airplane in flight. The construction of control surfaces is

similar to that of the wing. Control surfaces are usually made of an aluminum alloy structure built around a single spar member or torque tube. Ribs are fitted to the spar at the leading and trailing edges and are joined together with a metal strip. The ribs, in most cases, are formed from flat sheet stock. They are not solid, but contain punched lightening holes which save weight but do not reduce strength. On helicopters, the flight control surfaces include main and tail rotor blades and the stabilizer. Refer to chapter 10 for additional information on flight control surfaces.

Section III. AERODYNAMIC FORCES

9. General

An airframe repairman must repair, fabricate, and modify aircraft structures and must also know the names of all structural members and parts, their locations and purposes, and the methods and techniques for repairing these parts. Basic flight theory and aerodynamics were considered in full detail when the aircraft was designed; however, the repairman should know this information and consider how a repair might affect these principles. It will be necessary for the repairman to repair exterior surfaces of the aircraft. All of these are critical aerodynamic

surfaces. They must be repaired so that the air will pass over them as smoothly as possible. Wing leading edges, wing upper and lower surfaces, and control surfaces are some of the more important areas which must be aerodynamically smooth. The repairman must make repairs that are not only structurally sound but also aerodynamically smooth. An understanding of the design and purpose of aircraft structures, along with the theory of flight principles, is important. The smoothness of repairs to these surfaces will be determined by the repairman's capability.

10. The Four Forces

Four forces have an effect on an aircraft while on the ground, during takeoff and landing, and in flight. These four forces are weight, lift, thrust, and drag.

a. Weight. Weight is the force exerted by an aircraft from the pull of gravity. It acts on an aircraft through the center of gravity. The magnitude of this force changes only with a change in gross weight.

b. Lift. If the forces of weight, thrust, and drag were the only ones acting on the aircraft, it would move down the runway until it ran out of runway or out of fuel. A force then is needed which will overcome the pull of weight and permit the aircraft to leave the ground. This fourth force, the one which works against the force of weight, is called lift. The wings are the part of an aircraft through which lift is obtained. How this lift is obtained is, like thrust, simple in theory but complex to understand and carry out.

c. Thrust. Thrust is the forward force produced by the engine through the propeller or, in jet engines, by the reaction of exhaust gases.

d. Drag. Inertia is that property of matter which causes an object to remain stationary or in uniform motion in a straight line until compelled to change direction by a force acting upon it. In other words, if the aircraft is set in motion by applying the force of thrust, it will remain in motion, in a straight line, until a force is applied to stop it. This stopping force is present in the resistance of the air itself to the passing of an aircraft through it. This resistance of the air represents a force which is called drag. Thrust, then, is the force which sets an aircraft in motion and keeps it in motion against the force of drag. Thrust can overcome the inertia of an aircraft to get it moving and can overcome the force of drag to keep it moving.

(1) *Airfoil.* To properly understand lift, the term airfoil should be understood. An airfoil is any surface designed to obtain a reaction upon itself from the air through which it passes. From the standpoint of an aircraft, such things as propeller blades, wings, stationary and movable control surfaces, and even the fuselage can be termed airfoils. The term is usually applied to the wings of an aircraft. In figure 15, several cross sections of wings or airfoils are shown. The front edge of a wing is called the leading edge, and the rear the trailing edge. The chord of a wing is the distance from the leading edge to the trailing edge and is represented by a straight line called the chord line. The curve or departure from such a straight line (which the shape of the wing takes) is known as the camber.

If the surface produces a convex (outward curving) surface, the camber is said to be positive. If concave (inward curving), the camber is said to be negative. The upper surface of an airfoil always has positive camber; the lower usually has positive camber also, but it can have zero (no curve) or negative camber.

(2) *Bernoulli's principle.* In the 18th century a Swiss physicist Bernoulli, through experimentation, discovered the fact that as the speed of air moving over a surface increases, the pressure on the surface decreases proportionately. How this fact applies to the flight of an aircraft can be explained as follows: As movement starts, the mass of air molecules at the leading edge of the airfoil divides. Since the distance across the curved top surface is greater than that across the relatively flat bottom surface, the air molecules which go over the top must move faster than those going across the bottom in order to meet at the same time along the trailing edge. The faster airflow across the wing will create a lower pressure above than below. This is shown in figure 16. The greater pressure below the wing tends to push into the lower pressure above. As long as air passes over the airfoil, this condition will exist. This is lift. When the movement of air is great enough, the lift will match the weight of the airfoil and all attached portions of it, and will then support the entire aircraft. As the speed of air across the wing increases even more, the lift exceeds the weight of the aircraft, and

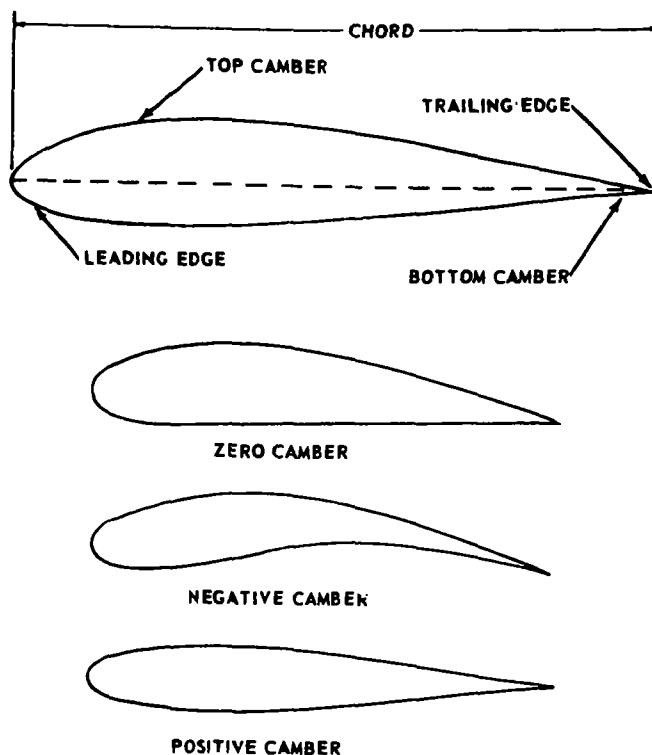


Figure 15. Airfoils in cross section.

the aircraft will rise. Not all the air met by an airfoil is used in lift. Some of it creates resistance or drag and hinders forward motion. Lift and drag, the two forces into which air resistance is converted, depend on the angle of attack, speed of the airfoil, air density, and shape of the airfoil or wing.

11. Angle of Attack

This is the acute angle between the chord of an airfoil and its direction of motion relative to the air. Motion relative to the air, or relative wind, is the direction of moving air in relation to the wing or airfoil (fig. 17).

Lift and drag increase with an increase in the angle of attack up to a certain point called the critical angle. At this point the wing suddenly loses lift, and, as a result, the aircraft stalls. Drag continues to increase. The cause of stalling is turbulence. Turbulence is created by eddies of air (bubbling) which break up the pattern of relative wind on the upper surface of the wing. Notice the eddying or bubbling of the air shown in figure 18. When the critical angle is

reached, the air no longer clings to the top of the wing, and turbulence slows down the speed of the relative wind and increases the pressure above the wing. With the loss of the pressure differential, the wing loses lift. At this point, the aircraft stalls. Wings and horizontal stabilizers are usually attached with a built-in angle of attack, known as the angle of incidence. When the fuselage is level longitudinally, the angle of incidence is measured between the chord of the wing and the horizontal plane.

12. Speed of the Airfoil

As the speed of the airfoil moving through the air increases, the difference in pressure between the upper and lower relative wind layers increases. So lift increases with speed, but not in direct proportion to it.

13. Air Density

The density of air at 18,000 feet is about one-half of that at sea level. Remember that air becomes thinner as altitude increases, so any aircraft flying at high altitudes must increase its speed to maintain level flight. An aircraft's flight is also affected by temperature, since air density decreases as air temperature increases.

14. Shape of an Airfoil

The shape of an airfoil affects lift in many ways. The greater the camber or curvature, up to a certain point, the greater the lift. An airfoil with a smooth surface has more lift in relation to drag than one with a rough surface. A rough surface produces turbulence, which reduces lift and increases drag.

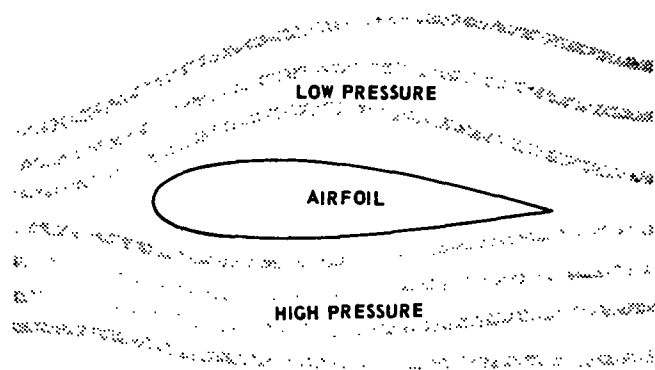


Figure 16. Lift.

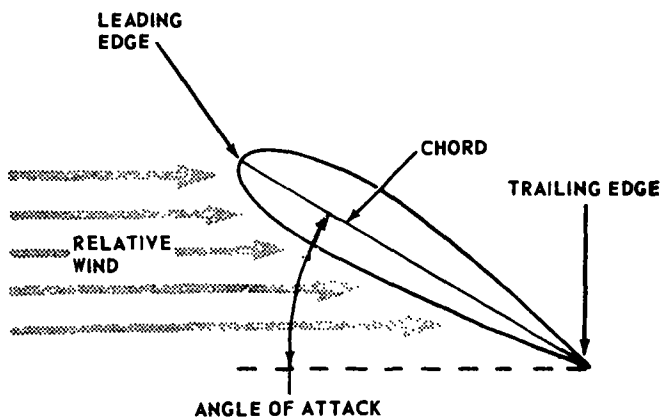


Figure 17. Angle of attack.

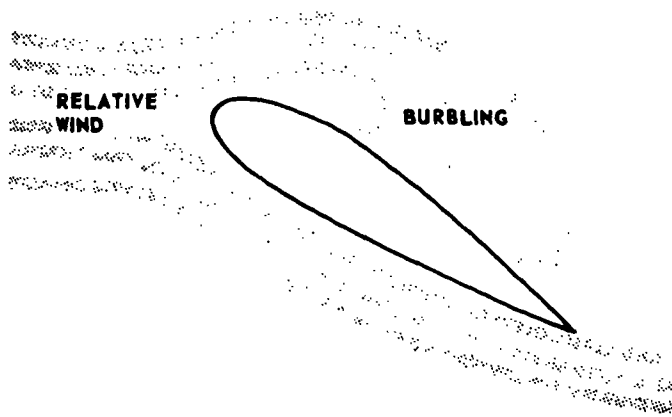


Figure 18. Critical angle of attack.

CHAPTER 3

AIRCRAFT STRUCTURAL METALS

Section I. PROPERTIES AND CHARACTERISTICS

15. General

Metallurgists have been working for almost a half century improving metals for use in aircraft construction. Each type of metal or alloy has certain properties and characteristics which make it desirable for a particular use, but it may have other qualities which are undesirable. The metallurgist's job is to build up the desirable qualities and tone down the undesirable ones. This is done by the alloying (combining) of metals and by various heat-treating processes. It is not necessary for the airframe repairman to be a metallurgist, but it is advantageous to have a general knowledge of the properties used in their development. The repairman should be familiar with a few metallurgical terms. The following terms are used in describing the physical properties and characteristics of metals.

a. Hardness. Hardness refers to the ability of a metal to resist abrasion, penetration, cutting action, or permanent distortion. Hardness may be increased by working the metal and, in the case of steel and certain aluminum alloys, by heat-treatment and cold working. Structural parts are often formed from metals in their soft state and are then heat-treated to harden them so that the finished shape will be retained. Hardness and strength are closely associated properties of metals.

b. Brittleness. Brittleness is the property of a metal which allows little bending or deformation without shattering. A brittle metal is apt to break or crack without change of shape. Because structural metals are often subjected to shock loads, brittleness is not a very desirable property. Cast iron or cast aluminum and very hard steel are brittle metals.

c. Malleability. A metal which can be hammered, rolled, or pressed into various shapes without cracking, breaking, or other detrimental effects, is said to be malleable. This property is necessary in sheet metal which is worked into curved shapes such as cowlings, fairings, and wingtips. Copper is an example of a malleable metal.

d. Ductility. Ductility is the property of a metal which permits it to be permanently drawn, bent, or twisted into various shapes without breaking. This property is essential for metals used in making wire and tubing. Ductile metals are greatly preferred for aircraft use because of their ease of forming and resistance to failure under shock loads. For this reason, aluminum alloys are used for cowl rings, fuselage and wing skin, and formed or extruded parts such as ribs, spars, and bulkheads. Chrome-molybdenum steel is also easily formed into desired shapes. Ductility is similar to malleability.

e. Elasticity. Elasticity is that property which enables a metal to return to its original shape when the force which causes the change of shape is removed. This property is extremely valuable, as it would be highly undesirable to have a part permanently distorted after an applied load was removed. Each metal has a point known as the elastic limit beyond which it cannot be loaded without causing permanent distortion. In aircraft construction, members and parts are so designed that the maximum loads to which they are subjected will never stress them beyond their elastic limits. This desirable property is present in spring steel.

f. Toughness. A material which possesses toughness will withstand tearing or shearing and may be stretched or otherwise deformed without breaking. Toughness is a desirable property in aircraft metals.

g. Conductivity. Conductivity is the property which enables a metal to carry heat or electricity. The heat conductivity of a metal is especially important in welding, as it governs the amount of heat that will be required for proper fusion. Conductivity of the metal, to a certain extent, determines the type of jig to be used to control expansion and contraction. In aircraft, electrical conductivity must also be considered in conjunction with bonding, to eliminate radio interference. Metals vary in their capacity to conduct heat. Copper, for instance, has a relatively high

rate of heat conductivity and is a good electrical conductor.

h. Fusibility. Fusibility is the ability of a metal to become liquid by the application of heat. Metals are fused in welding. Steels fuse at approximately 2500°F. (1371°C.), and aluminum alloys fuse at approximately 1100°F. (593°C.).

i. Density. Density is the weight of a unit volume of a material. In aircraft work, the actual weight of a material per cubic inch is preferred, as this figure can be used in determining the weight of a part before actual manufacture. Density is an important consideration when choosing a material to be used in the design of a part in order to maintain the proper weight and balance of the aircraft.

j. Contraction and Expansion. Contraction and expansion are reactions produced in metals as the result of heating or cooling. A high degree of heat applied to a metal will cause it to expand or become larger. Cooling hot metal will shrink or contract it. Contraction and expansion affect the design of welding jigs, castings, and tolerances necessary for hot rolled material.

k. Strength. Strength refers to the ability of a metal to hold loads (or forces) without breaking. Strength is a property that sums up many of the desirable qualities of metals. Strength with toughness (*f* above) is the most important combination of properties a metal can possess. Metals having this combination of properties are used in vital structural members that may become overloaded in service.

16. Stress and Strain

In a discussion of metal properties, stress and strain should be mentioned. Stress is a force placed upon a body and is measured in terms of force per unit area, the force being expressed in pounds and the unit of area in square inches; in other words, pounds per square inch, abbreviated psi. Stress may be in the form of compression, tension, torsion, bending, shearing loads, or a combination of two or more of these. All parts of an aircraft are subjected to stresses. When a part fails to return to its original form after being stressed, it is said to be strained. The various stresses acting on parts of an aircraft, while in flight, have an important bearing on the metals used.

a. Tension. Tension is the resistance to pulling apart or stretching produced by two forces pulling in opposite directions along the same straight line. (fig. 19). The cables of a control system are placed under tension when the controls are operated.

b. Compression. Compression is the resistance to pushing together or crushing produced by two forces pushing toward each other in the same straight line (fig. 19). The landing struts of an aircraft are under compression when landing and, to a smaller degree, when supporting the weight of the aircraft as it rests on the ground.

c. Torsion. Torsion is the resistance to twisting (fig. 19). A torsional force is produced when

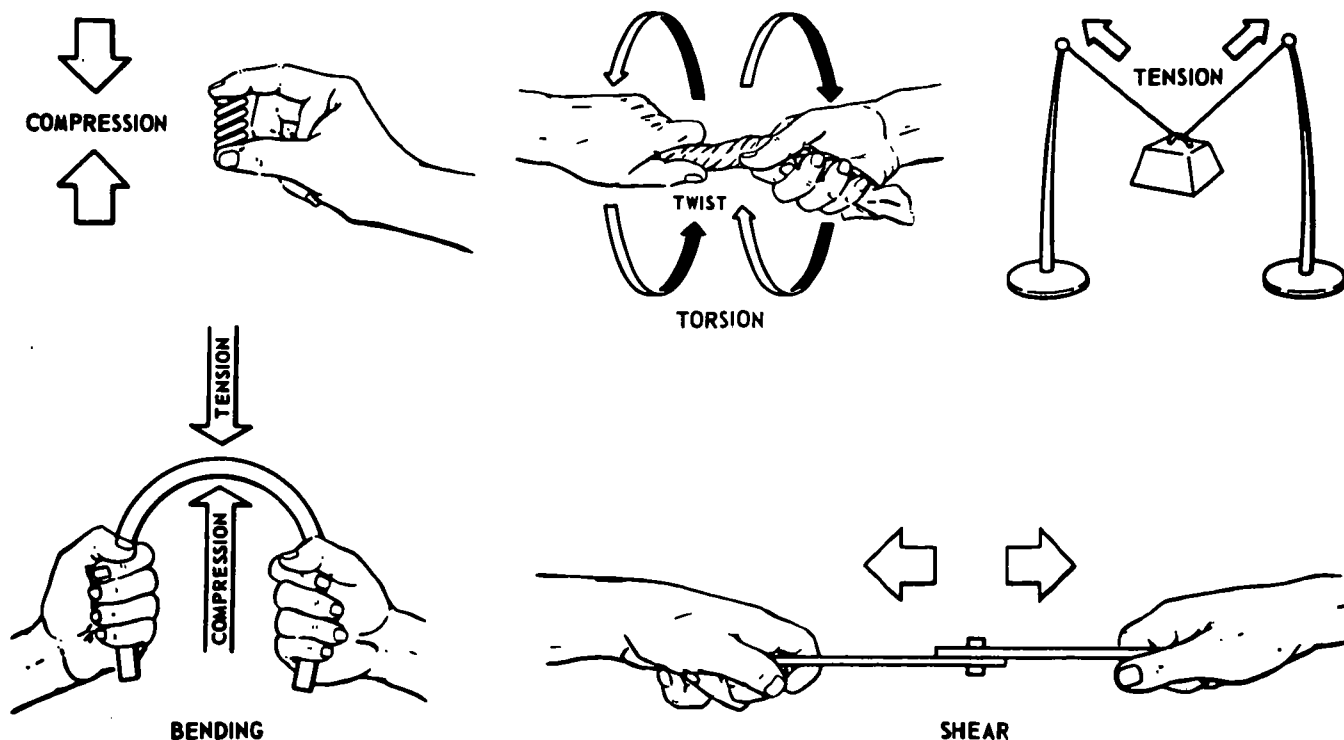


Figure 19. Examples of stress and strain.

an engine turns a crankshaft. Torque is the force that produces torsion.

d. Bending. Bending is a combination of tension and compression. The inside curve of the bent object is under compression, and the outside curve is under tension (fig. 19). The main spars of the main rotor blades are subjected to bending. The blades droop while the rotor head is at rest and bend upward when rotating.

e. Shear. Shear is the stress exerted when two pieces of metal fastened together are separated by sliding one over the other in opposite directions (fig. 19). The stress cuts off a bolt or a rivet like a pair of shears. In general, rivets are subjected to shear only; bolts, to both shear and tension. There is internal shear in most bending elements and in the skin of sheet metal structures.

Section II. METALWORKING PROCESSES

17. Alloying

a. An alloy has been defined as a metallic substance which contains more than one chemical element. Logically, this definition is unsatisfactory because no metallic element can be obtained in a condition of absolute purity, and, if applied strictly, the definition would result in all nominally pure metals being classified as alloys. The definition is acceptable on the understanding that, when dealing with nearly pure metals, there is no sharp dividing line between an impure metal and an alloy. Most alloys consist essentially of two or more metallic elements. Nonmetallic elements may also be present, notably carbon, nitrogen, oxygen, phosphorus, and sulfur. These are often accidental impurities introduced from the original one or during production of the alloy. In some cases, however, such as that of carbon in steel or cast iron, the nonmetallic element is an essential constituent, the presence of which determines the properties of the alloy.

b. Industrial alloys are classed as ferrous, (iron base) and nonferrous; the ferrous alloys, having iron as the main constituent, form the larger group. The most important ferrous alloys are those of iron and carbon, and where the carbon content is less than .13 percent by weight, they are known as steels, while cast iron and malleable iron contain 2 to 5 percent carbon by weight. The term *alloy steel* and *special steel* are used to describe steels in which metals other than iron are present in relatively large amounts; one such steel is stainless steel which contains chromium and nickel. Of the nonferrous alloys, those of copper have been known since the Bronze Age. The brasses are essentially alloys of copper and zinc; the copper content usually varies between 57 and 70 percent by weight. The bronzes are essentially alloys of copper with 5 to 10 percent tin by weight. Expansion of the aircraft industry has led to the development of light alloys, of which those of aluminum and magnesium are the most important. With increasing speed of flight of aircraft,

great interest has been attached to the use of titanium and titanium base alloys, which have a melting point considerably higher than that of aluminum or magnesium.

c. The most common way of preparing alloys is by the melting together of the constituent metals. If the melting point of metals differ widely, or if one is relatively very reactive, it may be convenient to prepare first a master alloy, portions of which are then melted with the remaining metals. According to the nature of the alloy, the melting process may be carried out in furnaces fired by gas, coke, or oil. Electrical heating, by resistance, induction, or arc-melting methods, is also used. A few alloys are prepared directly by the process in which the metals are extracted from their ores. Thus, pig iron is prepared by the reduction of iron ore in the blast furnace, and steels are prepared by the further purification of pig iron. Alloys may also be prepared by mixing finely divided powders of the constituent metals, and compacting the mixture under high pressure, followed by removal of the impurities.

18. Heat-Treatment

Heat-treatment is a series of operations involving the controlled heating and cooling of metals in the solid state. Its purpose is to change a mechanical property or combination of mechanical properties so that the metal will be more useful, serviceable, and safe for a definite purpose. By heat-treating, a metal can be made harder, stronger, and more resistant to impact. Heat-treating can also make a metal softer and more ductile. No one heat-treating operation can produce all of these characteristics. In fact, some properties are often improved at the expense of others. In being hardened, for example, a metal may become brittle. The various heat-treating processes are similar in that they all involve the heating and cooling of metals. They differ, however, in the temperatures to which the metal is heated, the rate at which it is cooled, and of course, in the final result.

a. Forms of Heat-Treatment. The most common forms of heat-treatment for ferrous metals are hardening, tempering, annealing, normalizing, and casehardening. Most nonferrous metals can be annealed and many of them can be hardened by heat-treatment. However, there is only one nonferrous metal, titanium, that can be casehardened, and none can be tempered or normalized.

(1) *Hardening.* For most steels, the hardening treatment consists of heating the steel to the correct temperature and then cooling it rapidly by plunging the hot steel into oil, water, or brine. Although most steels must be cooled rapidly for hardening, a few may be cooled in air from the hardening temperature. Hardening increases the hardness and strength of the steel but makes it less ductile. Many nonferrous metals also can be hardened and increased in strength by heating them to the proper temperatures and cooling rapidly. In the case of nonferrous metals, however, the process is called heat-treatment rather than hardening.

(2) *Tempering.* After the hardening treatment, steel is often harder than necessary and is too brittle for most practical uses. In addition, severe internal stresses are set up during the rapid cooling from the hardening temperature. To relieve the internal stresses and reduce brittleness, steel is tempered after being hardened. Tempering consists of heating the steel to a certain temperature (below that at which it was hardened), holding the metal at that temperature for the required length of time, and then cooling it, usually in still air. The resultant strength, hardness, and ductility depend on the temperature to which the steel is heated during the tempering process.

(3) *Annealing.* In general, annealing is the opposite of hardening. Metals are annealed to relieve internal stresses, soften them, make them more ductile, and refine their grain structures. Annealing consists of heating the metal to the proper temperature for the required length of time, and then cooling it back to room temperature. The rate at which the metal is cooled from the annealing temperature varies greatly. To produce maximum softness in steel, the metal must be cooled very slowly. This is accomplished by burying the hot part in sand, ashes, or some other substance that does not conduct heat readily, or by shutting off the furnace and allowing the furnace and part to cool together. The former method is called packing; the latter is called furnace cooling.

(4) *Normalizing.* The normalizing treatment applies to ferrous metals only. Normalizing

consists of heating the part to the proper temperature, holding it at that temperature until it is uniformly heated, and then removing it from the furnace and cooling it in still air. Steel parts are normalized to relieve the internal stresses set up by machining, forging, bending, or welding.

(5) *Casehardening.* Casehardening produces a hard, wear-resistant surface or case over a strong, tough core. The principal forms of casehardening are carburizing, cyaniding, and nitriding.

b. Principles of Heat-Treatment.

(1) *Internal structure of metals.* The results that may be obtained by heat-treatment depend to a great extent on the structure of the metal and on the manner in which the structure changes when the metal is heated and cooled. A pure metal cannot be hardened by heat-treatment because there is little change in its structure when heated. On the other hand, most alloys respond to heat-treatment, as their structures change with heating and cooling. An alloy may be in the form of a solid solution, a mechanical mixture, or a combination of a solid solution, a mechanical mixture, or a combination of a solid solution and a mechanical mixture. When an alloy is in the form of a solid solution, the elements and compounds which form the alloy are absorbed, one into the other, in much the same way that salt is dissolved in a glass of water, and the constituents cannot be identified even under a microscope. When two or more elements or compounds are mixed but can be identified by microscope examination, a mechanical mixture is formed. A mechanical mixture might be compared to the mixture of sand and gravel in concrete. The sand and gravel are both visible. Just as the sand and gravel are held together and kept in place by the matrix of cement, the other constituents of an alloy are embedded in the matrix formed by the base metal. An alloy which is in the form of a mechanical mixture at ordinary temperatures may change to a solid solution when heated. When cooled back to normal temperature, the alloy may return to its original structure. On the other hand, it may remain a solid solution or form a combination of a solid solution and mechanical mixture. An alloy which consists of a combination of solid solution and mechanical mixture at normal temperatures may change to a solid solution when heated. When cooled, the alloy may remain a solid solution, return to its original structure, or form a complex solution.

(2) *Behavior of steel during heating and cooling.* Changing the internal structure of a

ferrous metal is accomplished by heating to a temperature above its critical point, holding it at that temperature for a time sufficient to permit certain internal changes to occur, and then cooling to atmospheric temperature under predetermined, controlled conditions. At ordinary temperatures, the carbon in steel exists in the form of particles of iron carbide scattered throughout an iron matrix known as *ferrite*. The number, size, and distribution of these particles determines the hardness of the steel. At elevated temperatures, the carbon is dissolved in the iron matrix in the form of a solid solution called *austenite*, and the carbide particles appear only after the steel has been cooled. If the cooling is slow, the carbide particles are relatively coarse and few. In this condition the steel is soft. If the cooling is rapid, as by quenching in oil or water, the carbon precipitates as a cloud of very fine carbide particles and the steel is hard. The fact that the carbide particles can be dissolved in austenite is the basis of the heat-treatment of steel. The temperatures at which this transformation takes place are called the critical points and vary with the composition of the steel. The element normally having the greatest influence is carbon. Figure 20 shows graphically the relationship between the structural changes in carbon steel and the carbon content of the steel. In figure 20, line BFH represents the low critical points (the temperatures at which transformation from a mechanical mixture to a solid solution begins). Line CEFH represents the second critical points (the temperatures at which the change from alpha iron to gamma iron occurs). Line DEFH represents the upper critical points (the temperatures at which the transformation to austenite is complete). Note that line BFH, which represents the lower critical points in carbon steels, is horizontal. This shows that the lower critical points do not vary with carbon content. Line CEFH, which represents the second critical points, also runs horizontal to approximately 0.52 percent carbon (line CE), then dips downward until the carbon content reaches 0.80 percent. This shows that the temperatures drop as the carbon content is increased from 0.52 to 0.80 percent, and then remain unchanged as the carbon content is further increased. The upper critical points, represented by line DEFH, decrease as the carbon content increases, until a percentage of 0.80 is reached, and then remain unchanged with a further increase in carbon content.

19. Hot Working

Almost all steel is hot worked from the ingot into some form from which it is either hot or

cold worked to the finished shape. When an ingot is stripped from its mold, its surface is solid, but the interior is still molten. The ingot is then placed in a soaking pit which retards loss of heat and the molten interior gradually solidifies. After soaking, the temperature is equalized throughout the ingot, after which it is reduced to intermediate size by rolling, making it more readily handled. The rolled shape is called a *bloom* when its section dimensions are 6 by 6 inches or larger, and approximately square. The section is called a *billet* when it is approximately square and less than 6 by 6 inches. Rectangular sections which have widths greater than twice their thicknesses are called *slabs*. The slab is the intermediate shape from which sheets are rolled.

a. Castings. Castings are produced by pouring a melted metal or mixture of metals into a mold, where it is allowed to solidify. Castings are made in two types of molds, single-purpose molds and permanent molds. The single-purpose molds have to be specially prepared, sometimes by means of machines, from patterns for each casting. The use of metal or permanent molds offers many advantages where the process is applicable. The constantly repeated cost of sand molding is eliminated, but against this must be set the high initial cost of the metal mold or die. The latter is justified only where the same casting is required in great numbers. For many metals there is also a distinct advantage in regard to structure and strength which results from the relatively rapid solidification which takes place in a metal or chill mold. For the nonferrous metals, chill casting is extensively practiced, especially in the case of some aluminum alloys.

b. Hot Rolling. Blooms, billets, or slabs are heated above the critical range and rolled into a variety of shapes of uniform cross-section. The more common of these rolled shapes are sheet bar, channels, angles, I-beams, and the like. Sheet bar and rods rolled from steel are used extensively in aircraft work. Hot rolled material is frequently finished by cold rolling or drawing to obtain finish dimensions and a bright, smooth surface.

c. Forging. Complicated sections which cannot be rolled, or sections of which only a small quantity is required, are usually forged. Forging of steel is a mechanical working above the critical range to shape the metal as desired. Forging is done either by pressing or hammering the heated steel until the desired shape is obtained. Pressing is used when the parts to be forged are large and heavy; and this process also replaces hammering where high grade steel is required. Since a press is slow acting, its force is uni-

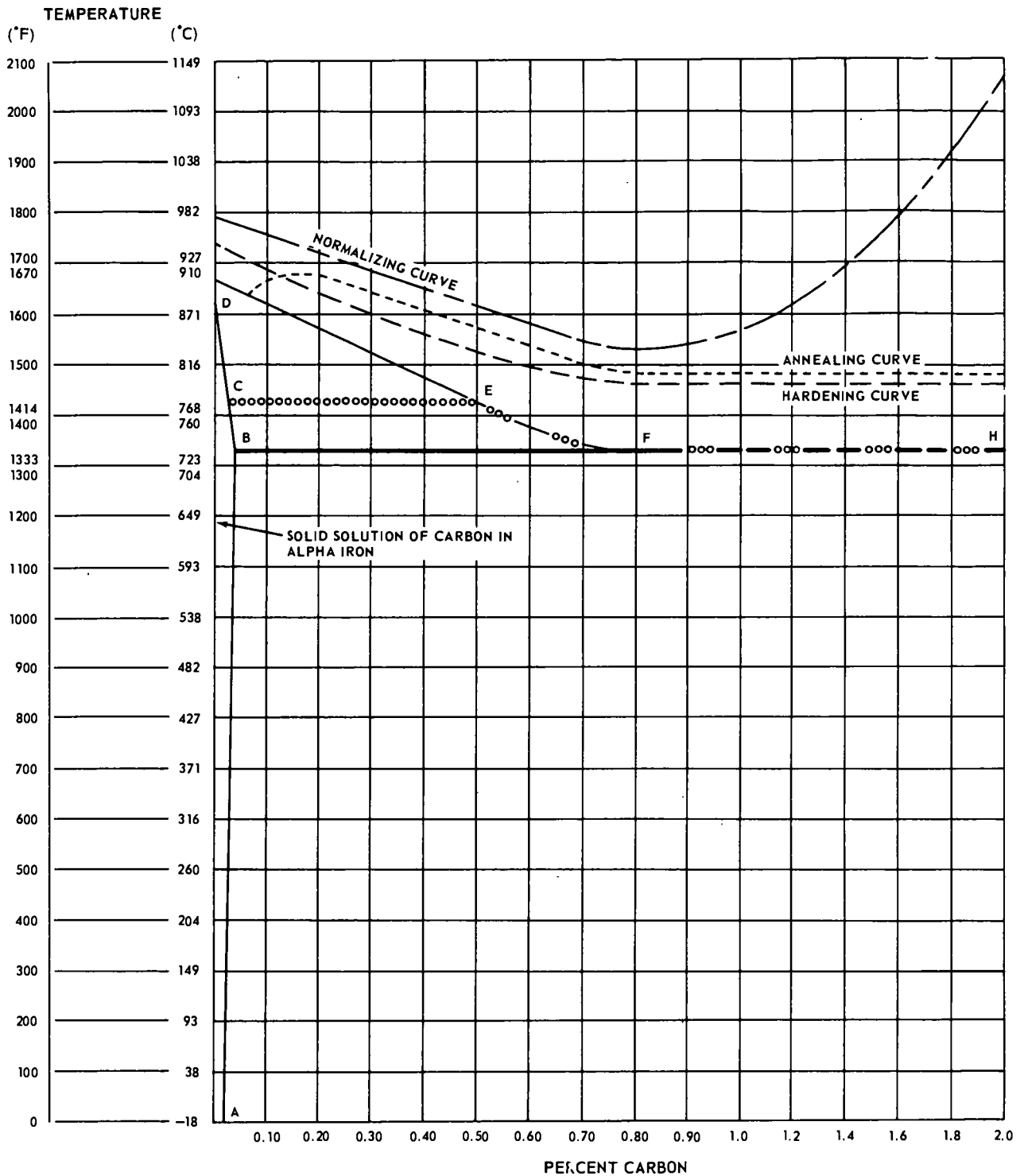


Figure 20. Iron-carbon diagram for steel.

formly transmitted to the center of the section, thus affecting the interior grain structure as well as the exterior to give the best possible structure throughout. Hammering can be used only on relatively small pieces. Since hammering transmits its force almost instantly, its effect is limited to a small depth. Thus, it is necessary to use a very heavy hammer or to subject the

part to repeated blows to insure complete working of the section. If the force applied is too weak to reach the center, the finished forged surface will be concave. If the center was properly worked, the surface will be convex or bulged. The advantage of hammering is that the operator has control over both the amount of pressure applied and the finishing temperature, and is

able to produce parts of the highest grade. This type of forging is usually referred to as smith forging. It is used extensively where only a small number of parts are needed. Considerable machining and material are saved when a part is smith forged to approximately the finished shape.

d. Extruding. The extrusion process involves the forcing of metal through an opening in a die, thus causing the metal to take the shape of the die opening. Some metals such as lead, tin, and aluminum may be extruded cold, but generally metals are heated before the operation is begun. The principal advantage of the extrusion process is in its flexibility. Aluminum, because of its workability and other favorable properties, can be economically extruded to more intricate shapes and larger sizes than is practicable with many other metals. Extruded shapes are produced in very simple as well as extremely complex sections. A cylinder of aluminum, for instance, is heated to 750° to 850°F. (399° to 454°C.) and is then forced through the opening of a die by a hydraulic ram. Many structural parts, such as stringers, are formed by the extrusion process.

20. Cold Working

Cold working applies to mechanical working performed at temperatures below the critical range. It results in a strain-hardening of the metal. In fact, the metal becomes so hard that it is difficult to continue the forming process without softening the metal by annealing. Since the errors attending shrinkage are eliminated in cold working, a much more compact and better metal is obtained. The strength and hardness, as well as the elastic limit, are increased, but the ductility decreases. Since this makes the metal more brittle, it must be heated from time to time during certain operations to remove the undesirable effects of the working. While there are several cold working processes, the ones with which the airframe repairman will be principally concerned are cold rolling, cold drawing, stamping, and pressing. These processes give the metals desirable qualities which cannot be obtained by hot working.

a. Cold Rolling. Cold rolling usually refers to the working of metal at room temperature. In this operation, the materials that have been rolled to approximate sizes are pickled to remove the scale, after which they are passed through chilled finishing rolls. This gives a smooth surface and also brings the pieces to accurate dimensions. The principal forms of cold rolled stocks are sheets, bars, and rods.

b. Cold Drawing. Cold drawing is used in making seamless tubing, wire, streamlined tie

rods, and other forms of stock. Wire is made from hot rolled rods of various diameters. These rods are pickled in acid to remove scale, dipped in lime water, and then dried in a steam room where they remain until ready for drawing. The lime coating adhering to the metal serves as a lubricant during the drawing operation. The size of the rod used for drawing depends upon the diameter desired in the finished wire. To reduce the rod to the desired size, it is drawn cold through a die. One end of the rod is filed or hammered to a point and slipped through the die opening. Here it is gripped by the jaws of the draw and pulled through the die. This series of operations is done by a mechanism known as a drawbench. In order to reduce the rod gradually to the desired size, it is necessary to draw the wire through successively smaller dies. Because each of these drawings reduces the ductility of the wire, it must be annealed from time to time before further drawings can be accomplished. Although cold working reduces the ductility, it increases the tensile strength of the wire enormously. In making seamless steel aircraft tubing, the tubing is cold drawn through a ring shaped die with a mandrel or metal bar inside the tubing to support it while the drawing operations are being performed. This forces the metal to flow between the die and the mandrel and affords a means of controlling the wall thickness and the inside and outside diameters.

c. Stamping and Pressing. Forming sheet metal parts by forcing the flat metal into molds or dies is called stamping or pressing. In the broader sense, there is no difference in meaning between the two terms. The term *stamping*, however, is generally understood to apply to the forming of small objects which can be shaped by one rapid blow of a machine, whereas the term *pressing* is applied to the process that utilizes a slow, steady stroke or blow to form a large section. The machinery used for these processes includes hydraulic, mechanical, and manually operated presses and drop hammers. Fabrication of parts by stamping and pressing brings the aviation industry one step nearer to mass production. Constant changes in aircraft design, however, make it necessary to alter or replace the dies frequently. For this reason, it is desirable, where possible, to avoid the use of steel dies. Steel dies give long service but there is considerable expense involved in their manufacture. Fortunately, the material from which most parts are stamped is relatively soft, permitting the use of dies made from materials more easily shaped than steel. One material which has proven successful in the construction of form-

ing dies is laminated hardwood. Such woods as birch and maple can be laminated to make as large a block as desired and can be given suitable shape with woodworking tools. One die is given the concave form and is called the female die. The male die is convex and shaped to match the female die exactly, allowing for the thickness of the metal to be formed. Although the blanks from which the dies are made are comparatively inexpensive, the actual construction of the die requires a high degree of woodworking skill. Hardwood dies are not, as a rule, as successful on drop hammers as they are on presses. The sudden impact of the hammer tends to deform the dies; therefore, lead-zinc dies are used extensively with the drop hammer. Normally, the female zinc die is clamped to the base of the hammer and the male lead die to the drop. This combination has proved very successful in that the lead die is soft enough to give slightly under the force of impact, thereby exerting equal pressure on all parts of the material being formed. The lead die will retain its shape for a considerable length of time because at each impact it is hammered against the hard zinc die, thus reshaping the lead to its original form.

21. Steel

Steel is the name given to the various alloys of iron with comparatively small proportions of carbon, silicon, manganese, sulfur, and phosphorus. Special steels usually contain, in addition, a large proportion of the rare element which gives it the special name, such as chromium steel, tungsten steel, manganese steel, nickel steel, and vanadium steel. There are many kinds and grades of steel used in aircraft construction, each having a characteristic or property which makes it suitable for some particular part. Steels for aircraft use range in tensile strength from 55,000 pounds per square inch to more than four times that strength.

a. Composition of Steel.

(1) *Carbon.* Carbon is by far the most important element found in steel. Carbon mixes with iron to form iron carbide, which is a compound known as *cementite*. Because of the amount of carbon, and its behavior when added to iron, steels can be heat-treated to various degrees of strength and toughness. The higher the carbon content, the greater will be the ultimate strength, hardness, and range through which it can be heated. At the same time, the ductility, malleability, toughness, impact resistance, and the weldability will be reduced as the carbon increases. A high carbon steel is therefore required where great hardness is demanded and where ductility is of secondary importance; a

low carbon steel is necessary if deep drawing or excessive mechanical working is required without excessive strength. Generally, low carbon steels are used for formed fittings and welded parts, and high carbon steels are used for springs. Steels in the medium carbon range are used for forged fittings and tie rods, where both strength and ductility are required.

(2) *Manganese.* Next to carbon in importance as an element in steel production is manganese. The main purpose of manganese is to eliminate the oxides and sulfur from steel in order to produce a clean, tough metal, hardening the material through to the core. The addition of manganese improves the forging qualities of the steel by reducing the brittleness at forging and rolling temperatures.

(3) *Silicon.* Silicon is a nonmetallic element which is used in steel making as a hardener and deoxidizer (to remove rust). When used in small quantities, the element improves the ductility of the steel.

(4) *Sulfur.* Sulfur is a very undesirable impurity which must be limited in amount to not more than 0.06 percent. The presence of sulfur renders steel brittle at rolling or forging temperatures. Manganese combines with sulfur to form manganese sulfide and thus counteracts the effects of sulfur. When too much sulfur is present, an iron sulfide is formed which, because of its lower melting point, is in liquid form at the forging temperature of steel.

(5) *Phosphorus.* Phosphorus raises the yield strength and improves the resistance to atmospheric corrosion in low carbon steels, but is limited in amount to not more than 0.05 percent. Greater amounts cause brittleness when the metal is cold.

(6) *Nickel.* Nickel, a white metal almost as bright as silver, adds strength and hardness, and increases the yield strength of nickel steels. In heat-treatment, the presence of nickel in the steel slows down the critical rate of hardening which, in turn, increases the depth of hardening and produces a finer grain structure. Nickel also reduces the tendency to warp and scale, and increases the corrosion resistance of steel. Nickel is one of the principal constituents of stainless or corrosion-resistant steels.

(7) *Chromium.* Chromium is a hard, gray metal with a high melting point. This element imparts hardness, strength, wear resistance, and corrosion resistance to steel. Chromium also improves the magnetic qualities of steel to such an extent that chromium steel is used for magnets. The main use of chromium in alloys is in conjunction with nickel, tungsten, molybdenum, and

vanadium. Some chromium alloys are used for parts where great wear resistance is required. Thus a chromium-vanadium alloy is used for ball bearings and a tungsten-chromium alloy is used for high-speed cutting tools.

(8) *Molybdenum*. Molybdenum alloys itself very well with steel to produce a wide variety of molybdenum steels. A small percentage of this element has as great an effect as much larger quantities of their alloying agents. This element reduces the grain size and increases the elastic limit, impact value, wear resistance, and fatigue strength of steels. The molybdenum steels are readily heat-treated, forged, and machined.

(9) *Vanadium*. Vanadium, the most expensive of the alloying elements, improves the grain structure and increases the ultimate strength, yield point, toughness, resistance to impact, vibration, and stress reversal of steels. Vanadium is seldom used in amounts exceeding 0.20 percent, and when used with chromium, produces a chrome-vanadium steel with excellent ductility and high strength characteristics.

(10) *Tungsten*. Tungsten steels have no direct application in aircraft construction but possess an interesting property known as *red hardness* (the characteristic of a cutting tool to retain its cutting edges even when heated to red hot temperature).

(11) *Titanium*. Titanium is added in small quantities to stainless steel which is to be used for exhaust stacks, tailpipe shrouds, or other parts where intense heat is encountered. Titanium aids in reducing brittleness caused by high operating temperatures.

b. Types of Steel.

(1) *Carbon steels*. Steel containing carbon in percentages ranging from 0.10 to 0.30 percent is classed as low carbon steel. The equivalent SAE numbers range from 1010 to 1030. (Identification of steel by the SAE numbering system is explained in *c*(1) below.) Steels of this grade are used for the manufacture of articles such as safety wire, certain nuts, cable bushings, and threaded rod ends. In sheet form, this steel is used for secondary structural parts and clamps; in tubular form, it is used for moderately stressed structural parts. Steel containing carbon in percentages ranging from 0.30 to 0.50 percent is classed as medium carbon steel. This steel is especially adaptable for machining, forging, and where surface hardness is important. Certain rod ends, light forgings, and parts such as woodruff keys are made from SAE 1035 steel. Steel containing carbon in percentages ranging from 0.50 to 1.05 percent is classed as high car-

bon steel. The addition of other elements in varying quantities adds to the hardness of this steel. The addition of other elements in varying quantities adds to the hardness of this steel. In the fully heat-treated condition it is very hard and will withstand high shear and wear, but little deformation. It has limited use in aircraft construction. In sheet form, SAE 1095 is used for making flat springs; in wire form, it is used for making coil springs.

(2) Alloy steels.

(a) *Chromium steels*. Chromium steel is high in hardness, strength, and corrosion-resistant properties. SAE 51335 steel is particularly adaptable for heat-treated forging which require greater toughness and strength than may be obtained in plain carbon steel.

(b) *Chrome-molybdenum steels*. Molybdenum in small percentages is used in combination with chromium to form chrome-molybdenum steel, which has various uses in aircraft. Molybdenum is a strong alloying element and raises the ultimate strength of steel without affecting ductility or workability. Molybdenum steels are tough and wear-resistant and harden throughout from heat-treatment. They are especially adaptable for welding, and for this reason are used principally for welded structural parts and assemblies. This type steel has practically replaced carbon steel in the fabrication of fuselage tubing, engine mounts, landing gears, and other structural parts. For example, a heat-treated SAE X4130 tube is approximately four times as strong as an SAE 1025 tube of the same weight and size. The popular series of chrome-molybdenum steel is that series containing 0.25 to 0.55 percent carbon, 0.15 to 0.25 percent molybdenum, and 0.50 to 1.10 percent chromium. These steels, when suitably heat-treated, are deep hardening, easily machined, readily welded by either gas or electric methods, and are especially adapted to high temperature service.

(c) *Chrome-vanadium steels*. Chrome-vanadium steels are made of approximately 0.18 percent vanadium and about 1 percent chromium. When heat-treated, these steels have strength, toughness, and resistance to wear and fatigue. A special grade of this steel in sheet form can be cold formed into intricate shapes and can be folded and flattened without signs of breaking or failure. SAE 6150 is used for making springs; and chrome-vanadium with high carbon content, SAE 6195, is used for ball and roller bearings.

(d) *Nickel steels*. The various nickel steels are produced by combining nickel with carbon steel. Steels containing from 3 to 3.75 percent nickel are commonly used. Nickel in-

creases the hardness, tensile strength, and elastic limit of steel without appreciably decreasing the ductility. It also intensifies the hardening effect of heat-treatment. SAE 2330 steel is used extensively for aircraft parts such as bolts, terminals, keys, clevises, and pins.

(e) *Nickel-chrome steels.* Nickel and chromium in various proportions mixed with steel form the nickel-chrome steels. The general proportion is about two and one-half times as much nickel as chromium. Both nickel and chromium influence the properties of steel; nickel toughens it, while chromium hardens it. Nickel-chrome steel is used for machined and forged parts requiring strength, ductility, toughness, and shock resistance. These steels include the SAE 3140, 3250, and 3435 types.

(f) *Stainless steels.* Stainless steels are corrosion-resisting metals. The anticorrosive degree of this steel is determined by the surface condition of the metal as well as by the composition, temperature, and concentration of the corrosive agent. The main constituent of stainless steel is chromium, to which nickel may or may not be added. The corrosion-resisting steel that is perhaps most often used in aircraft and missile construction is known as 18-8 steel, because it contains 18 percent chromium and 8 percent nickel. One of the distinctive features of this steel is that its strength may be increased only by cold working. Stainless steels may be rolled, drawn, bent, or formed to any number of shapes. Because these steels expand about 50 percent greater and conduct heat only about 40 percent as rapidly as mild steels, they are more difficult to weld than are mild steels. Some of the common applications of stainless steel are fabrication of exhaust collectors, stacks, and manifolds, structural and machined parts, springs, castings, and tie rods and cables.

c. Identification.

(1) *SAE numbering system.* The steel classification of the Society of Automotive Engineers (SAE) is used in specifications for all high grade steels used in automotive and aircraft construction. A numerical index system identifies the composition of SAE steels. Each SAE number consists of a group of digits, the first of which represents the type of steel; the second, the percentage of the principal alloying element; and, usually, the last two or three digits the percentage, in hundredths of 1 percent, of carbon in the alloy. Table 1 lists the basic SAE numerals for the more common steels. Examples of the application of this numbering system are as follows:

(a) 4150. This indicates a molybdenum steel containing approximately 1 percent chrom-

ium, 0.15 to 0.25 percent molybdenum, and 0.50 percent carbon.

(b) 1010. A carbon steel having no principal alloying element but containing 0.10 percent carbon.

Note. The percentages indicated in the SAE numbers are average; for example, the carbon content of SAE 1050 steel may vary from 0.45 to 0.55 percent.

(2) *Identification by marking.* A visual means of identifying steel by SAE number is by color code. The colors are placed side by side and in sequence so that when read from the nearest end of the tube, bar, rod, sheet, or plate

Table 1. SAE Numerals Used in Identification of Steels

Type of steel	Classification (Series)
Carbon	1000
Nickel	2000
Nickel-chromium	3000
Molybdenum	4000
Chromium	5000
Chromium-vanadium	6000
Tungsten	7000
Silicon-manganese	9000

toward the middle, the material designation is shown. The colors of each band and its corresponding digit or digits in the SAE numbering system are shown in table 2.

(3) *Types.* Steel stock is manufactured in several forms and shapes, including sheet, bars, rods, tubing, and wire. Sheet metal is made in a number of sizes and thicknesses. Bars and rods are supplied in a variety of shapes, such as round, square, rectangular, hexagonal, and octagonal. Tubing can be obtained in round, oval, rectangular, and streamlined shapes. The size of tubing is generally specified by outside diameter and wall thickness. Refer to table 3 for identification of the various forms of steel.

(4) *Identification by spark test.* Spark testing is a common means of identifying various ferrous metals which have become mixed together in a scrap pile. In this test, the piece of iron or steel is held against a revolving grinding stone and the metal is identified by the sparks thrown off. Each ferrous metal has its own peculiar spark characteristics. The spark streams vary from a few tiny shafts to a shower of sparks several feet in length. Wrought iron produces long shafts that are straw colored as they leave the stone and white at the end. Cast iron sparks are red as they leave the stone and turn to a straw color. Low carbon steels give off long straight shafts having a few white sprigs. As the carbon content of the steel increases,

Table 2. Cross-reference of Old and New Color Codes

STEEL		
First digits, steel no.	Old color (broad stripe)	New color
10	Red	Blue and black
13	Red and yellow	Blue and olive drab
23	Yellow	Green and olive drab
25	Yellow and green	Green and orange
31	Green	Olive drab and blue
40	Green and white	Yellow and black
41	Black and white	Yellow and blue
43	Blue and white	Yellow and olive drab
46	Red and black	Yellow and red
61	White	Red and blue
86	Black and yellow	White and red
87	Black and green	White and maroon
Last digits, steel no.	Old color (narrow stripe)	New color
00	Red and black	Black and black
10	Red	Blue and black
12	Red and green	Blue and green
15	Red and white	Blue and orange
20	Yellow	Green and black
25	Yellow and white	Green and orange
30	Black	Olive drab and black
35	Black and white	Olive drab and orange
40	Green	Yellow and black
45	Green and white	Yellow and orange
50	Blue	Orange and black
55	Blue and brown	Orange and orange
60	Brown	Red and black
65	Brown and white	Red and orange
95	Olive drab	Gray and orange

the number of sprigs along each shaft increases and the stream becomes whiter in color. Nickel steel causes the spark stream to contain small white blocks of light within the main burst.

d. working Practices

(1) *General heat-treating practices.* The first important consideration in the heat-treatment of a steel part is to know its chemical composition. This, in turn, determines its critical range. When the critical range is known, the next consideration is the rate of heating and cooling to be used. The carrying out of these operations involves the use of uniform-heating furnaces, proper temperature controls, and suitable quenching mediums.

(a) *Heating.* The aim in heating is to transform pearlite to austenite as the steel is heated through the critical range. Since this transition takes time, a relatively slow rate of heating must be employed. Ordinarily, the cold steel is inserted when the temperature in the furnace is 300° to 500°F. (149° to 260°C.) below the hardening temperature. In this way,

too rapid heating through the critical range is prevented.

(b) *Soaking.* The temperature of the furnace must be held constant during the soaking period, as it is during this period that rearrangement of the internal structure of the steel takes place. Soaking temperatures for various types of steel are specified in ranges varying from 50° to 100°F. (10° to 38°C.). Small parts are soaked in the lower part of the specified range and heavy parts in the upper part of the specified range. The length of the soaking period depends upon the type of steel and the size of the part. Naturally, heavier parts require longer soaking to insure equal heating throughout. As a general rule, a soaking period of 30 minutes to 1 hour is sufficient for the average heat-treating operation. Table 4 indicates in a general way the effect of size on time required for soaking. This table is intended to be used as a guide only and should not be construed as being a mandatory requirement. The table applies only to plain carbon and low alloy steels.

(c) *Cooling.* The rate of cooling through the critical range determines the form that the steel will retain. Various rates of cooling are employed to produce the desired results. Still air is a slow cooling medium, but is much faster than furnace cooling. Liquids are the fastest cooling media and are therefore used in hardening steels. There are three commonly used quenching liquids: brine, water, and oil. Brine is the most severe medium, water is next and oil is the least severe. Generally, an oil quench is used for alloy steels, and brine or water for carbon steels. The tendency of steel to warp and crack during the quenching process is difficult to overcome because certain parts of the article cool more rapidly than others. The following recommendations will greatly reduce the warping tendency:

1. An article should never be thrown into the quenching bath. By permitting it to lie on the bottom of the bath, it is apt to cool faster on the top side than on the bottom side, thus causing it to warp or crack.

2. The article should be agitated slightly to destroy the coating of vapor which might prevent it from cooling rapidly. This allows the bath to convey its heat to the atmosphere.

3. Irregular shaped articles should be immersed in such a manner that the heavy end enters the bath first.

(2) *Specific heat-treatments for steels.*

(a) *Hardening.* Pure iron, wrought iron, and extremely low carbon steels cannot be

Table 3. Identification of Steel

Commercial designation	Current specification	Condition available
Low carbon	QQ-S-698	Hot rolled or cold rolled. See specification for temper and finish.
Low carbon (High strength)	MIL-S-7809	Hot rolled, cold rolled, as rolled, or annealed.
1020	MIL-S-7952	Cold rolled and annealed.
1025	MIL-S-7952	Same as 1020
1095	MIL-S-7947	A (Annealed)
4130	MIL-S-18729	H (Hard temper) (C47 to C52)
6150	MIL-S-18731	A (Annealed)
8630	MIL-S-18728	MA (Modified annealed)
8735	MIL-S-18730	N (Normalized)
18-8	MIL-S-5059	Annealed
301 (High ductility)	MIL-S-5059	1/4-Hard 1/2-Hard 3/4-Hard Hard
18-8	MIL-S-5059	Annealed
302 (General use)	MIL-S-4043	1/4-Hard
304 (Low carbon)	MIL-S-5059	Annealed and pickled only
18-8	MIL-S-5059	Annealed
316 (Corrosion-resistant)	MIL-S-6721	1/4-Hard
Comp. Ti, Cb, or Cb-Ta.		Sheet—Solution heat-treated, pickled, and cold rolled (No. 20 finish) Strip—Cold rolled, solution heat-treated, and pickled (No. 1 strip finish) Plate—Hot rolled, solution heat-treated, and pickled

BARS AND RODS

Commercial designation	Current specification	Physical condition	Surface condition
Carbon steels (general purpose) (Specify type desired) 1095	QQ-S-633	Hot rolled and cold finish (specify condition and finish)	
	MIL-S-8559	A (As forged) B (As rolled) C (Spheroidized)	(1) Black as forged or rolled. (2) Pickled or blast cleaned. (3) Rough turned. (4) Cold finish. (5) Surface ground.
	MIL-S-8695	Furnished in C-4 condition 1-inch diameter or thickness and under, and C-2 condition over 1-inch diameter or thickness unless otherwise specified. A (As forged) B (As rolled)	

Table 3. Identification of Steel—Continued

Commercial designation	Current specification	Physical condition	Surface condition
		C (Annealed) D (Normalized) E (Normalized and tempered) F (Hardened and tempered) G (Drawn and normalized) H (Normalized and spheroidize annealed) Furnished in condition C-4 1½ inch diameter or thickness and under, and C-2 condition over 1½ inch diameter or thickness unless otherwise specified.	
4130	MIL-S-6758	A (As forged) B (As rolled) C (Annealed) D (Normalized) E (Normalized and tempered) F Hardened and tempered)	Same as 1095
4140	MIL-S-5626	Same as 4130	Same as 1095
4340 or E4340	MIL-S-5000	Same as 4130	Same as 1095
6150	MIL-S-8503	Same as 4130 (A through E)	Same as 1095
8620	MIL-S-8690	A (As forged) B (As rolled) C (Annealed) D (Normalized) E (Normalized and tempered) Furnished in C-4 condition 1½ inch diameter or thickness and under, and C-2 condition over 1½ inch diameter or thickness unless otherwise specified.	(1) Black as forged or rolled (2) Pickled or blast cleaned (3) Rough turned (4) Cold finish
8630	MIL-S-6050	Same as 4130	Same as 1095
8735	MIL-S-6098	Same as 4130	Same as 1095
8740	MIL-S-6049	Same as 4130	Same as 1095
18-8	MIL-S-7720	A (Annealed)	A (Scale not removed) (hot finish)
	Comp G	B (Annealed and cold finished)	B (Pickled or blast cleaned)
		C (Hot rolled or forged only)	C (Cold drawn)
			D (Cold rolled)
			E (Turned) (rounds only)
			F (Centerless ground) (round only)
			G (Polished) (round only)
304	QQ-S-763	A (Annealed)	A (Scale not removed) (hot finish) (pickled or blast clean and pickled rough turned) (round bars only)
		B (Cold finish) (High tensile)	B (Cold drawn or cold rolled) (centerless ground or smooth turned and polished) (round bars only)
321	QQ-S-763	A (Annealed)	A (Same as 304)
410	QQ-S-763	A (Annealed)	A (Same as 304)
430	QQ-S-763	A (Annealed)	A (Same as 304)
16CR-2Ni	MIL-S-18732	Type A—Annealed	Descaled
431 (Special quality)		Type HT 175 (175,000 PSI)	
		Type HT 115 (115,000 PSI)	

Table 3. Identification of Steel—Continued

TUBING				
Commercial designation	Current specification	Type	Shape	Conditions
1025	MIL-T-5066	I. Welded	Round and other shapes	Normalized, cold drawn or stress relieved
4130	MIL-T-6731	II. Seamless Welded	I. Round II. Rectangular and square III. Streamline IV. Oval	A (Annealed) N (Normalized) HT-125 (125,000 PSI Minimum) HT-150 (150,000 PSI Minimum) HT-180 (180,000 PSI Minimum)
4130	MIL-T-6736	Seamless	Same as 4130	A (Annealed) N (Normalized) HT-125 HT-150 HT-180
4135	MIL-T-6735	Seamless	Same as 4130	A (Annealed) N (Normalized) HT-125 HT-150 HT-180 HT-200
8630	MIL-T-6734	Seamless	Same as 4130	A (Annealed) N (Normalized) HT-125 HT-150 HT-180
8630	MIL-T-6732	Seamless	Same as 4130	A (Annealed) N (Normalized) HT-125 HT-150 HT-180
8735	MIL-T-6733	Seamless	I. Round II. Rectangular and square III. Streamline IV. Oval	A (Annealed) N (Normalized) HT-125 (125,000 PSI Minimum) HT-150 (150,000 PSI Minimum) HT-180 (180,000 PSI Minimum)
304	MIL-T-5695	Seamless or welded	As required	1/4-Hard cold drawn 1/2-Hard cold drawn Annealed only 1/4-Hard
304	MIL-T-8506	Seamless or welded	As required	
304 (Hydraulic)	MIL-T-6845	Seamless or welded	Round	Annealed only
304 (Hydraulic)	MIL-T-8504	Seamless or welded	Round	
18-8 Inconel	MIL-T-7840	Seamless or welded	Round	Cold drawn
321 18-8	MIL-T-6737	Welded	As required	Annealed only
G321 18-8	MIL-T-8606	Seamless or welded drawn	As required	Annealed only
X347	MIL-T-6737	Welded	As required	Annealed only
G347 18-8	MIL-T-8606	Seamless or welded drawn	As required	Annealed only

Table 3. Identification of Steel—Continued

WIRE				
Commercial designation	Current specification	Type	Physical condition	Surface condition
Hard-drawn	4-7-59	A (Spring) B (Zinc-coated)		Class A—uncoated Class B—zinc-coated
General purpose	QQ-W-412 QQ-W-428	I. II. III.	A (Spheroidize annealed at finish size) B (Spheroidize annealed and lightly drawn)	I. Oil tempered spring wire II. Hard drawn III. Soft
302 and 316 410 and 420	QQ-W-423 QQ-W-423 QQ-W-461	I. Light II. Medium III. Heavy	Spring temper Heat-treated Zinc-coated	Corrosion-resistant annealed Corrosion-resistant annealed Hard annealed
Music Wire 6150	QQ-W-470 MIL-S-8696	A (Annealed) B (Spring temper)	Cold drawn Corrosion-resistant	1. Cold finished 2. Ground

Cb-Columbium (Niobium)
Ta-Tantalum
Ti-Titanium

appreciably hardened by heat-treatment, as they contain no hardening element. Cast iron can be hardened, but its heat treatment is limited. When cast iron is cooled rapidly, it forms white iron, which is hard and brittle. When cooled slowly, it forms gray iron, which is soft but brittle under impact. In plain carbon steel, the maximum hardness depends almost entirely on the carbon content of the steel. As the carbon content increases, the ability of the steel to be hardened increases. However, this increase in hardenability with an increase in carbon content continues only to a certain point. In practice, that point is 0.80 percent carbon content. When the carbon content is increased beyond 0.80 percent, there is no increase in hardenability, but there is an increase in wear resistance. This increase in wear resistance is due to the formation of hard cementite. To harden steel, it must be heated to a temperature just above the upper critical point, soaked at that temperature long enough to insure an austenitic condition throughout the steel, and then cooled rapidly. As can be seen from the iron-carbon diagram in figure 20, the hardening range for low carbon steel is approximately the same as the annealing range. As the carbon content increases, the hardening range decreases nearly parallel to both the annealing range and the upper critical points. When hardening carbon steel, remember that the steel must be cooled to below 1,000°F. (538°C.) in less than one second. Should the temperature drop to 1,000°F. (538°C.) exceed 1 second, the austenite begins to transform into

fine pearlite. This pearlite varies in hardness, but is much harder than the pearlite formed by annealing and much softer than the martensite desired. After the 1,000°F. (538°C.) temperature is reached, the rapid cooling must continue if the final structure is to be all martensite. When alloys are added to steel, the time limit for the temperature drop to 1,000°F. (538°C.) increases above the 1-second limit for carbon steels. Therefore, a slower quenching medium will produce hardness in alloy steels. Because of the high internal stresses in the *as quenched* condition, steel must be tempered just before it becomes cold. The part should be removed from the quenching bath at a temperature of approximately 200°F. (93°C.), as the temperature range from 200°F. (93°C.) down to room temperature is the cracking range. Hardening temperatures and quenching mediums for the various types of steel are listed in table 5. When heating steel, the temperature should be determined by the use of accurate instruments. At times, however, such instruments are not available, and in such cases, the temperature of the steel may be judged approximately by its color. The accuracy with which temperatures may be judged by color depends on the experience of the repairman, the light in which the work is being done, the character of the scale on the steel, the amount radiated light within the furnace, and the emissivity or tendency of steel to radiate or emit light. Refer to table 6 for the colors of steels at various temperatures.

(b) *Tempering.* Tempering reduces the

Table 4. Soaking Period for Hardening, Normalizing, and Annealing

Thickness of largest section of unit (in.)	Approximate time	
	Heating (hr)	Holding (hr)
Up to 1	$\frac{3}{4}$	$\frac{1}{2}$
1 to 2	$1\frac{1}{4}$	$\frac{1}{2}$
2 to 3	$1\frac{3}{4}$	$\frac{3}{4}$
3 to 4	$2\frac{1}{4}$	1
4 to 5	$2\frac{3}{4}$	1
5 to 8	$3\frac{1}{2}$	$1\frac{1}{2}$

brittleness imparted by hardening and produces definite physical properties within the steel. Tempering always follows, never precedes, the hardening operation. In addition to reducing brittleness, tempering softens the steel. Tempering is always conducted at temperatures below the low critical point of the steel. In this respect, tempering differs from annealing, normalizing, and hardening, in which the temperatures are above the upper critical point. When hardened steel is reheated, tempering begins at 212°F. (100°C.) and continues as the temperature increases toward the low critical point. By selecting a definite tempering temperature, the resulting hardness and strength can be predetermined. Approximate temperatures for various tensile strengths are listed in table 5. The minimum time at the tempering temperature should be 1 hour. If the part is over 1 inch in thickness, the time should be increased by 1 hour for each additional inch of thickness. Tempered steels, as used in aircraft work, have from 100,000 to 200,000 psi ultimate tensile strength. Generally, the rate of cooling from the tempering temperature has no effect on the resulting structure; therefore, the steel is usually cooled in still air after being removed from the furnace. As in the case of hardening, tempering temperatures may be approximately determined by color. These colors appear only on the surface and are due to a thin film of oxide which forms on the metal. In order to see the tempering colors, the surface must be brightened. A buff stick consisting of a piece of wood with emery cloth attached is ordinarily used for this purpose. When tempering by the color method, an open flame or heated ironplate is ordinarily used as the heating medium. Although the color method is convenient, it should not be used unless adequate facilities for determining temperature are not obtainable. Refer to table 7 for color of carbon steel at various tempering temperatures.

(c) *Annealing.* Annealing of steel produces a fine-grained, soft, ductile metal without

internal stresses or strains. In the annealed state, steel has its lowest strength. Annealing of steel is accomplished by heating the metal to just above the upper critical point, soaking at that temperature, and cooling very slowly in the furnace itself. Refer to table 5 for recommended temperatures. Soaking time is approximately 1 hour per inch thickness of the material. Slow cooling is obtained by shutting off the heat and allowing the furnace and metal to cool together to 900°F. (482°C.) or lower, then removing the metal from the furnace and cooling in still air. Another method is to bury the heated steel in ashes, sand, or other substance that does not conduct heat readily.

(d) *Normalizing.* Normalizing of steel removes the internal stresses set up by heat-treating, welding, casting, forming, or machining. Stress, if not controlled, will lead to failure. Because of the better physical properties, aircraft steels are often used in the normalized state, but seldom, if ever, in the annealed state. One of the most important uses of normalizing in aircraft work is in welded parts. Welding causes strain to be set up in the adjacent material. In addition, the weld itself is a cast structure as opposed to the wrought structure of the rest of the material. These two types of structure have different grain sizes, and to refine the grain as well as to relieve the internal stresses, all welded parts should be normalized after fabrication. Normalizing is accomplished by heating the steel above the upper critical point and cooling in still air. The more rapid quenching obtained by air cooling, as compared to furnace cooling, results in a harder and stronger material than that obtained by annealing. Recommended normalizing temperatures for the various types of aircraft steels are listed in table 5.

(e) *Casehardening.* The object in casehardening is to produce a hard case over a tough core. Casehardening is ideal for parts which require a wear-resistant surface and, at the same time, must be tough enough internally to withstand the applied loads. The steels best suited to casehardening are the low carbon and low alloy steels. If high carbon steel is casehardened, the hardness penetrates the core and causes brittleness. In casehardening, the surface of the metal is changed chemically by introducing a high carbide or nitride content. The core is unaffected chemically. When heat-treated, the surface responds to hardening while the core toughens. The common forms of casehardening are carburizing, cyaniding, and nitriding. Since cyaniding is not used in aircraft work, only carburizing and nitriding will be discussed.

Table 5. Heat Treatment Procedures for Steels

STEEL NO.	TEMPERATURES						QUENCHING MEDIUM (N)	TEMPERING (DRAWING) TEMPERATURES FOR TENSILE STRENGTH									
	NORMALIZING		ANNEALING		HARDENING			100,000		125,000		150,000		180,000		200,000	
	°F	°C	°F	°C	°F	°C		°F	°C	°F	°C	°F	°C	°F	°C	°F	°C
1020	1650-1750	899-954	1600-1700	871-927	1575-1675	856-912	WATER	-	-	-	-	-	-	-	-	-	-
1022(X1020)	1650-1750	899-954	1600-1700	871-927	1575-1675	856-912	WATER	-	-	-	-	-	-	-	-	-	-
1025	1600-1700	871-927	1575-1650	856-899	1575-1675	856-912	WATER	(A)	(A)	-	-	-	-	-	-	-	-
1035	1575-1650	856-899	1575-1625	856-885	1525-1600	829-871	WATER	875	468	-	-	-	-	-	-	-	-
1045	1550-1600	843-871	1550-1600	843-871	1475-1550	800-843	OIL OR WATER	1150	621	-	-	-	-	(N)	(N)	-	-
1095	1475-1550	800-843	1450-1500	788-816	1425-1500	773-816	OIL	(B)	(B)	-	-	1100	593	850	454	750	399
2330	1475-1525	800-829	1425-1475	773-800	1450-1500	788-816	OIL OR WATER	1100	593	950	510	800	427	-	-	-	-
3135	1600-1650	871-899	1500-1550	816-843	1475-1525	800-829	OIL	1250	677	1050	566	900	482	750	399	650	343
3140	1600-1650	871-899	1500-1550	816-843	1475-1525	800-829	OIL	1325	718	1075	579	925	496	775	413	700	371
4037	1600	871	1525-1575	829-856	1525-1575	829-856	OIL OR WATER	1225	662	1100	593	975	524	-	-	-	-
4130(X4130)	1600-1700	871-927	1525-1575	829-856	1575-1625	856-885	OIL (C)	(D)	(D)	1050	566	900	482	700	371	575	301
4140	1600-1650	871-899	1525-1575	829-856	1525-1575	829-856	OIL	1350	732	1100	593	1025	551	825	440	675	357
4150	1550-1600	843-871	1475-1525	800-829	1500-1550	816-843	OIL	-	-	1275	690	1175	635	1050	566	950	510
4340(X4340)	1550-1625	843-885	1525-1575	829-856	1475-1550	800-843	OIL	-	-	1200	649	1050	566	950	510	850	454
4640	1675-1700	912-927	1525-1575	829-856	1500-1550	816-843	OIL	-	-	1200	649	1050	566	750	399	625	329
6135	1600-1700	871-927	1550-1600	843-871	1575-1625	856-885	OIL	1300	704	1075	579	950	510	800	427	750	399
6150	1600-1650	871-899	1525-1575	829-856	1550-1625	843-885	OIL	(D)(E)	(D)(E)	1200	649	1000	538	900	482	800	427
6195	1600-1650	871-899	1525-1575	829-856	1500-1550	816-843	OIL	(F)	(F)	-	-	-	-	-	-	-	-
NE8620	-	-	-	-	1525-1575	829-856	OIL	-	-	1000	538	-	-	-	-	-	-
NE8630	1650	899	1525-1575	829-856	1525-1575	829-856	OIL	-	-	1125	607	975	524	775	413	675	357
NE8735	1650	899	1525-1575	829-856	1525-1575	829-856	OIL	-	-	1175	635	1025	551	875	468	775	413
NE8740	1625	885	1500-1550	816-843	1500-1550	816-843	OIL	-	-	1200	649	1075	579	925	496	850	454
30905	-	-	(G)(H)	(G)(H)	(I)	(I)	-	-	-	-	-	-	-	-	-	-	-
51210	1525-1575	829-856	1525-1575	829-856	1775-1825(J)	967-995	OIL	1200	649	1100	593	(K)	(K)	750	399	-	-
51335	-	-	1525-1575	829-856	1775-1850	967-1010	OIL	-	-	-	-	-	-	-	-	-	-
52100	1625-1700	885-927	1400-1450	760-788	1525-1550	829-843	OIL	(F)	(F)	-	-	-	-	-	-	-	-
CORROSION RESISTING (16-2) (I)	-	-	-	-	-	-	-	(M)	(M)	-	-	-	-	-	-	-	-
SILICON CHROMIUM (FOR SPRINGS)	-	-	-	-	1700-1725	927-941	OIL	-	-	-	-	-	-	-	-	-	-

NOTES

- (A) DRAW AT 1150°F (621°C) FOR TENSILE STRENGTH OF 70,000 PSI.
- (B) FOR SPRING TEMPER DRAW AT 800° TO 900°F (427° TO 482°C) ROCKWELL HARDNESS C-40-45.
- (C) BARS OR FORGINGS MAY BE QUENCHED IN WATER FROM 1500° TO 1600°F (816° TO 871°C).
- (D) AIR-COOLING FROM THE NORMALIZING TEMPERATURE WILL PRODUCE A TENSILE STRENGTH OF APPROXIMATELY 90,000 PSI.
- (E) FOR SPRING TEMPER DRAW AT 850° TO 950°F (454° TO 510°C) ROCKWELL HARDNESS C-40-45.
- (F) DRAW AT 350° TO 450°F (177° TO 232°C) TO REMOVE QUENCHING STAINS. ROCKWELL HARDNESS C-40-45.
- (G) ANNEAL AT 1600° TO 1700°F (871° TO 927°C) TO REMOVE RESIDUAL STRESSES DUE TO WELDING OR COLD WORK. MAY BE APPLIED ONLY TO STEEL CONTAINING TITANIUM OR COLUMBIUM.
- (H) ANNEAL AT 1900° TO 2100°F (1039° TO 1149°C) TO PRODUCE MAXIMUM SOFTNESS AND CORROSION RESISTANCE. COOL IN AIR OR QUENCH IN WATER.
- (I) HARDENED BY COLD WORK ONLY.
- (J) LOWER SIDE OF RANGE FOR SHEET 0.06 INCH AND UNDER. MIDDLE OF RANGE FOR SHEET AND WIRE 0.125 INCH. UPPER SIDE OF RANGE FOR FORGINGS.
- (K) NOT RECOMMENDED FOR INTERMEDIATE TENSILE STRENGTHS BECAUSE OF LOW IMPACT.
- (L) FOR STEEL, MILITARY SPECIFICATION MIL-S-10732, IT IS RECOMMENDED THAT, PRIOR TO TEMPERING, CORROSION-RESISTING (16 Cr-2 Ni) STEEL BE QUENCHED IN OIL FROM A TEMPERATURE OF 1875° TO 1900°F (1024° TO 1033°C), AFTER A SOAKING PERIOD OF 1/2 HOUR AT THIS TEMPERATURE. TO OBTAIN A TENSILE STRENGTH AT 115,000 PSI, THE TEMPERING TEMPERATURE SHOULD BE APPROXIMATELY 525°F (274°C). A HOLDING TIME AT THESE TEMPERATURES OF ABOUT 2 HOURS IS RECOMMENDED. TEMPERING TEMPERATURES BETWEEN 700° AND 1100°F (371° TO 593°C) WILL NOT BE APPROVED.
- (M) DRAW AT APPROXIMATELY 800°F (427°C) AND COOL IN AIR FOR ROCKWELL HARDNESS OF C-50.
- (N) WATER USED FOR QUENCHING SHALL NOT EXCEED 65°F (10°C). OIL USED FOR QUENCHING SHALL BE WITHIN THE TEMPERATURE RANGE OF 60° TO 130°F (27° TO 44°C).

Table 6. Color Chart for Steel at Various Temperatures

Color of steel	Temperature of steel	
	(°F.)	(°C.)
Faint red	900	482
Blood red	1,050	566
Dark cherry	1,075	579
Medium cherry	1,250	677
Cherry or full red	1,375	746
Bright red	1,550	843
Salmon	1,650	899
Orange	1,725	941
Lemon	1,825	996
Light yellow	1,975	1,079
White	2,200	1,204
Dazzling white	2,350	1,288

Table 7. Color Chart for Carbon Steel at Various Tempering Temperatures

Color of oxide	Temperature of carbon steel	
	(°F.)	(°C.)
Pale yellow	428	220
Straw	446	230
Golden yellow	469	243
Brown	491	255
Brown dappled with purple	509	265
Purple	531	277
Dark blue	550	288
Bright blue	567	297
Pale blue	610	321

1. *Carburizing.* Carburizing is a case-hardening process in which carbon is added to the surface of low carbon steel. Thus, a carburized steel has a high carbon surface and a low carbon interior. When the carburized steel is heat-treated, the case is hardened while the core remains soft and tough. A common method of carburizing is that called *pack carburizing*. When carburizing is to be done by this method, the steel parts are packed in a container with charcoal or some other material rich in carbon. The container is then sealed with fire clay, placed in a furnace, heated to approximately 1,700°F. (927°C.), and soaked at that temperature for several hours. As the temperature increases, carbon monoxide gas forms inside the container and, being unable to escape, combines with the gamma iron in the surface of the steel. The depth to which the carbon penetrates depends on the length of the soaking period. For example, when carbon steel is soaked for 8 hours, the carbon penetrates to a depth of about 0.062 inch. In another method of carburizing, called *gas carburizing*, a material rich in carbon is introduced into the furnace atmosphere. The carburizing atmosphere is produced by the

use of various gases or by the burning of oil, wood, or other materials. When the steel parts are heated in this atmosphere, carbon monoxide combines with the gamma iron to produce practically the same results as those described under the pack carburizing process. A third method of carburizing is that of *liquid carburizing*. In this method, the steel is placed in a molten salt bath that contains the chemicals required to produce a case comparable with one resulting from pack or gas carburizing. Alloy steels with low carbon content as well as low carbon steels may be carburized by either of the three processes; however, some alloys, such as nickel, tend to retard the absorption of carbon. As a result, the time required to produce a given thickness of case varied with the analysis of the metal. The following steels are frequently used for carburized parts:

SAE no.	Core strength (psi)
1020	60,000
2320	80,000
2515	120,000
3115	85,000
3312	100,000
4615	80,000

2. *Nitriding.* Nitriding is unlike other casehardening processes in that, before nitriding, the part is heat-treated to produce definite physical properties. Thus, parts are hardened and tempered before being nitrided. Most steels can be nitrided, but special alloys are required for best results. These special alloys contain aluminum as one of the alloying elements and are called *nitralloys*. In nitriding, the part is placed in a special nitriding furnace and heated to a temperature of approximately 1,000°F. (538°C.). With the part at this temperature, ammonia gas is circulated within the specially constructed furnace chamber. The high temperature cracks the ammonia gas into nitrogen and hydrogen. The ammonia which does not break down is trapped in a water trap below the regions of the other two gases. The nitrogen reacts with the iron to form iron nitride. The iron nitride is dispersed in minute particles at the surface and works inward, the depth of penetration depending on the length of the treatment. The case, however, is extremely thin. In nitriding, soaking periods as long as 72 hours are frequently required to produce the desired thickness of case. Nitriding can be accomplished with a minimum of distortion, because of the low temperature at which parts are casehardened and because no quenching is required after exposure to the ammonia gas.

22. Aluminum and Aluminum Alloys

a. Description. Aluminum is found in most clays, soils, and rocks, but the principal commercial source is the ore, bauxite. Bauxite is largely aluminum oxide mixed with impurities. These impurities are removed by a chemical process leaving the pure aluminum oxide, alumina. An electrolytic process is used to obtain aluminum from the oxide. Aluminum is one of the most important metals in aircraft construction. It is vital to the aviation industry principally because of its high strength-to-weight ratio, its corrosive-resisting qualities, and its comparative ease in fabrication. The outstanding characteristic of aluminum is its light weight, which is one-third as much as the steel required to accomplish the same structural purpose. Commercially pure aluminum has a tensile strength of more than 9,000 pounds per square inch, but by rolling or other cold-working processes, its strength may be approximately doubled. By alloying the metal with other metals, together with the use of heat-treating processes, the tensile strength may be raised to as high as 80,000 psi or to within the strength range of structural steel. The principal alloying elements are copper, silicon, magnesium, zinc, nickel, iron, chromium, and manganese. These metals are added singly or in combination to produce the desired characteristics. The total percentage of alloying elements is seldom more than 6 to 10 percent in the wrought alloys. Further changes can be brought about by heat treating. Aluminum and aluminum alloys are available in two basic forms, wrought alloys and cast alloys. Of these two, the wrought alloys are the most widely used in aircraft construction. However, wrought aluminum is always derived from cast aluminum by heating the cast form to a specified temperature and reshaping it by rolling, forging, or extruding while it is in the heated condition.

The extruding process makes possible the production of many shapes, and eliminates much machining, forming, and bending.

b. Identification. Aluminum products are identified by a universally used designation system, recently adopted by the Aluminum Association. Under this new arrangement, wrought aluminum and wrought aluminum alloys are designated by a four digit index system. The first digit of the designation indicates the major alloying element or alloy group, as shown in table 8. Thus, 1xxx indicates aluminum 99.000 percent or greater, 2xxx indicates an aluminum alloy in which copper is the major alloying element, 3xxx indicates an aluminum alloy with manganese as the major alloying element, etc. Although most aluminum alloys contain several

Table 8. Designation for Aluminum Alloy Groups

Aluminum	99.00 percent minimum and greater	1xxx
Aluminum	Copper	2xxx
Alloys	Manganese	3xxx
grouped	Silicon	4xxx
by	Magnesium	5xxx
major	Magnesium and silicon	6xxx
alloying	Zinc	7xxx
elements	Other element	8xxx

alloying elements, only one group (6xxx) designates more than one alloying element. In the 1xxx group the second digit in the designation indicates modifications in impurity limits. If the second digit is zero, it indicates that there is no special control on individual impurities. The last two of the four digits indicate the minimum aluminum percentage. Thus, alloy 1030 indicates 99.30 percent aluminum without special control on impurities. Alloys 1130, 1230, 1330, etc., indicate the same aluminum purity with special control on one or more impurities. Likewise, 1075, 1175, 1275, etc., indicate 99.75 percent aluminum. In the 2xxx through 8xxx groups, the second digit indicates alloy modifications. If the second digit in the designation is zero, it indicates the original alloy; while numbers 1 through 9, assigned consecutively, indicate alloy modifications. The last two of the four digits have no special significance but serve only to identify the different alloys in the group. Generally these digits are the same as those formerly used to designate the same alloy. Thus, 2-14 was formerly 14S, 3003 was 3S, and 7075 was 75S.

(1) *Temper designation.* The temper designation follows the alloy designation and shows the actual condition of the metal. It is always separated from the alloy designation by dash, as shown in table 9. The letter F following the alloy designation indicates the *as fabricated* condition, in which no effort has been made to control the mechanical properties. The letter O indicates dead soft, or annealed condition. The letter W indicates solution heat treated. Solution heat treatment consists of heating the metal to a high temperature followed by a rapid quench in cold water. This is an unstable temper, applicable only to those alloys which spontaneously age at room temperature. Alloy 7075 may be ordered in the W condition. The letter H indicates strain hardened; that is, cold worked, hand drawn, or rolled. Additional digits are added to the H to indicate the degree of strain hardening. Alloys in this group cannot be strengthened by heat treatment,

but are strengthened by cold working. The letter T indicates fully heat treated. Digits are added to the T to indicate certain variations in treatment.

(2) *Classification of wrought aluminum alloys.* Wrought aluminum alloys are classified as either heat treatable or nonheat treatable. As previously indicated, certain alloys may be hardened by heat treatment, while others may be hardened only by cold working. Those which can be hardened only by cold working are referred to as nonheat-treatable or strainhardened alloys. Heat treatable alloys may be hardened by heat treatment, by cold working, or by the application of both processes.

Table 9. Temper Designations for Aluminum Alloys

Designation	Condition Indicated	Example
-F	As fabricated	3003-F
-O	Fully annealed	6061-O
-W	Solution heat treated only ..	2024-W
-H	Strain hardened (cold worked)	
-H1, plus one or more digits	Strain hardened only and in an unstable condition ..	1100-H14
-H2, plus one or more digits	Strain hardened and then partially annealed	3003-H24
-H3, plus one or more digits	Strain hardened and then partially annealed	3003-H36
-T	Heat treated	
-T3	Solution heat treated and then cold worked	2024-T3
-T4	Solution heat treated	2024-T4
-T5	Artificially aged only	2017-T5
-T6	Solution heat treated and then artificially aged	2014-T6
-T8	Solution heat treated, cold worked, and then artificially aged	7075-T8
-T9	Solution heat treated, artificially aged, and then cold worked	6061-T9
-T10	Artificially aged and then cold worked	2014-T10

The -T designations above may have one or more digits added to denote certain variations of the basic heat treatments described.

(a) *Heat-treatable alloys.* Greater strength is obtainable in the heat-treatable alloys. Therefore, they are used for structural purposes in aircraft in preference to the nonheat-treatable alloys. Heat-treatable alloys commonly used in aircraft construction (in order of in-

creasing strength) are 5053, 6061, 6062, 6063, 2017, 2024, 2014, and 7075.

1. Alloys 5053, 6061, 6062, and 6063 are sometimes used for oxygen and hydraulic lines and in some applications as extrusions and sheet metal.

2. Alloy 2017 is used for rivets, stressed-skin covering, and other structural members.

3. Alloy 2024 is used for airfoil covering and fittings. It may be used wherever 2017 is specified, since it is stronger.

4. Alloy 2014 is used for extrusions and forging. This alloy is similar to 2017 and 2024 in that it contains a high percentage of copper. It is used where more strength is required than that obtainable from 2017 and 2024.

5. Alloy 7075 is a relatively new material differing from the other high-strength alloys in that zinc (instead of copper) is the main alloying element. Alloy 7075 is used where highest strength is necessary. Alloy 7075 contains a small amount of chromium as a stabilizing agent.

(b) *Nonheat-treatable alloys.* Non-heat-treatable alloys used in aircraft construction are 1100, 3003, and 5052. These alloys do not respond to any heat treatment other than by a softening, annealing effect. They may be hardened only by cold working.

1. Alloy 1100 is used where strength is not an important factor but where weight, economy, and corrosion resistance are desirable. This alloy is used for the fabrication and repair of fuel and oil tanks, fairings, and wingtips.

2. Alloy 3003 is similar to 1100 and is generally used for the same purposes. It contains a small percentage of manganese and is stronger and harder than 1100, but retains enough workability so that it is usually preferred over 1100 in most applications.

3. Alloy 5052 is used for fuel lines, hydraulic lines, fuel tanks, and wingtips. Substantially higher strengths without too much sacrifice of workability can be obtained in 5052. It is, therefore, preferred over 1100 and 3003 in many applications.

(3) *Corrosion resistance.* Aluminum is widely known for its remarkable resistance to corrosion, although some of the aluminum alloys are more resistant than others. When aluminum is in contact with air, a thin film of aluminum oxide forms on the surface as a protective barrier against any further attack. Often no additional protective coating is necessary but precautions are taken when the metal is exposed to severe atmospheric conditions or salt water. Interior surfaces are protected with zinc chromate primer. Exterior surfaces are primed and then painted. Where aluminum is in contact with

dissimilar metals, protective coatings are also essential, since such contacts are likely to cause electrolytic action.

(4) *Alclad sheet.* Alclad is the name given to standard aluminum alloys which have been coated on both sides with a thin layer of pure aluminum. Alclad has very good corrosion-resisting qualities and is used exclusively for exterior surfaces of aircraft. Alclad sheet is available in all tempers of 2014, 2017, 2024, and 7075.

(5) *Shop Characteristics.*

(a) *Forming.* Aluminum is one of the most workable of all the common commercial metals. It can be fabricated readily into a variety of shapes by any conventional method; however, formability varies a great deal with the alloy and temper. In general, the aircraft manufacturers form the heat-treatable alloys in the -O or -T4 condition before they have reached their full strength. They are subsequently heat-treated or aged to the maximum strength condition before installation in aircraft. By this combination of processes, the advantage of forming in a soft condition is obtained without sacrificing the maximum obtainable strength-weight ratio.

(b) *Annealing.* When aluminum is worked to any great extent, it becomes strain hardened. To remove this hardness, it is necessary to anneal the metal. The usual method for removing strain hardening due to cold work is to heat the metal to 650°F. (343°C.) and allow it to cool slowly in still air. To remove the effects of heat treatment, slightly higher temperatures are necessary.

(c) *Welding.* Aluminum is one of the most readily weldable of all metals. The non-heat-treatable alloys can be welded by all methods, and the heat-treatable alloys can be successfully spot welded. The melting point for pure aluminum is 1220°F. (660°C.), while various aluminum alloys melt at slightly lower temperatures. Aluminum products do not show any color even up to the melting point.

(d) *Riveting.* Riveting is the most reliable method of joining stress-carrying parts of heat-treated aluminum alloy structures.

(6) *Identification by marking.* The identification of small sizes of bars, tubing, and wire by specification number is impracticable, and a color code marking, consisting of painted stripes, has been established. There are ten colors used in this identification marking system of represent numbers 1, 2, 3, 4, 5, 6, 7, 8, 9, and 0. Refer to table 10. These ten colors are also used to represent letters F, H, O, T, W, A, B, C, D, and S. A combination of these colors, representing a combination of numbers and letters,

is used to mark material to denote its material designation. For example, aluminum alloy with

Table 10. Color Code

Color	Equivalent no.	Equivalent letter
Black	0	S
Blue	1	F
Green	2	H
Olive drab	3	O
Yellow	4	T
Orange	5	W
Red	6	A
Maroon	7	B
White	8	C
Gray	9	D

material designation 2218-T6 is marked green, space, green, blue, white, space, yellow, and red (fig 21). Another color code system has been established for certain aluminum alloys. A cross-reference from old to new color codes for these aluminum alloys is listed in table 11.

Table 11. Cross-Reference of Old and New

ALUMINUM		
Aluminum alloy no.	Old color	New color
1100	White	Green
3003	Green	Olive drab
2014	Gray	Blue and yellow
2024	Red	Green and yellow
6052	Purple	Orange and green
6053	Black	Orange and olive drab
6061	Blue and yellow	Red and blue
7075	Brown and yellow	Maroon and orange

(7) *Types.* The various types of aluminum alloy stock are listed in table 12.

(8) *Identification test.* If for any reason identification markings are not on the material, it is possible to separate the heat-treatable alloys from the nonheat-treatable alloys by immersing a sample of the material in a 10-percent solution of caustic soda (sodium hydroxide). The heat-treatable alloys will turn black due to the copper content, whereas the others will remain bright. In the case of clad material, the surface will remain bright but there will be a dark area in the middle when viewed from the edge.

c. *Working Practices.*

(1) *Heat-treating.* The most widely used heat-treatable alloys are the wrought alloys, Alclad 2017, 2024, Alclad 2024, 2025, 6053, 6061,

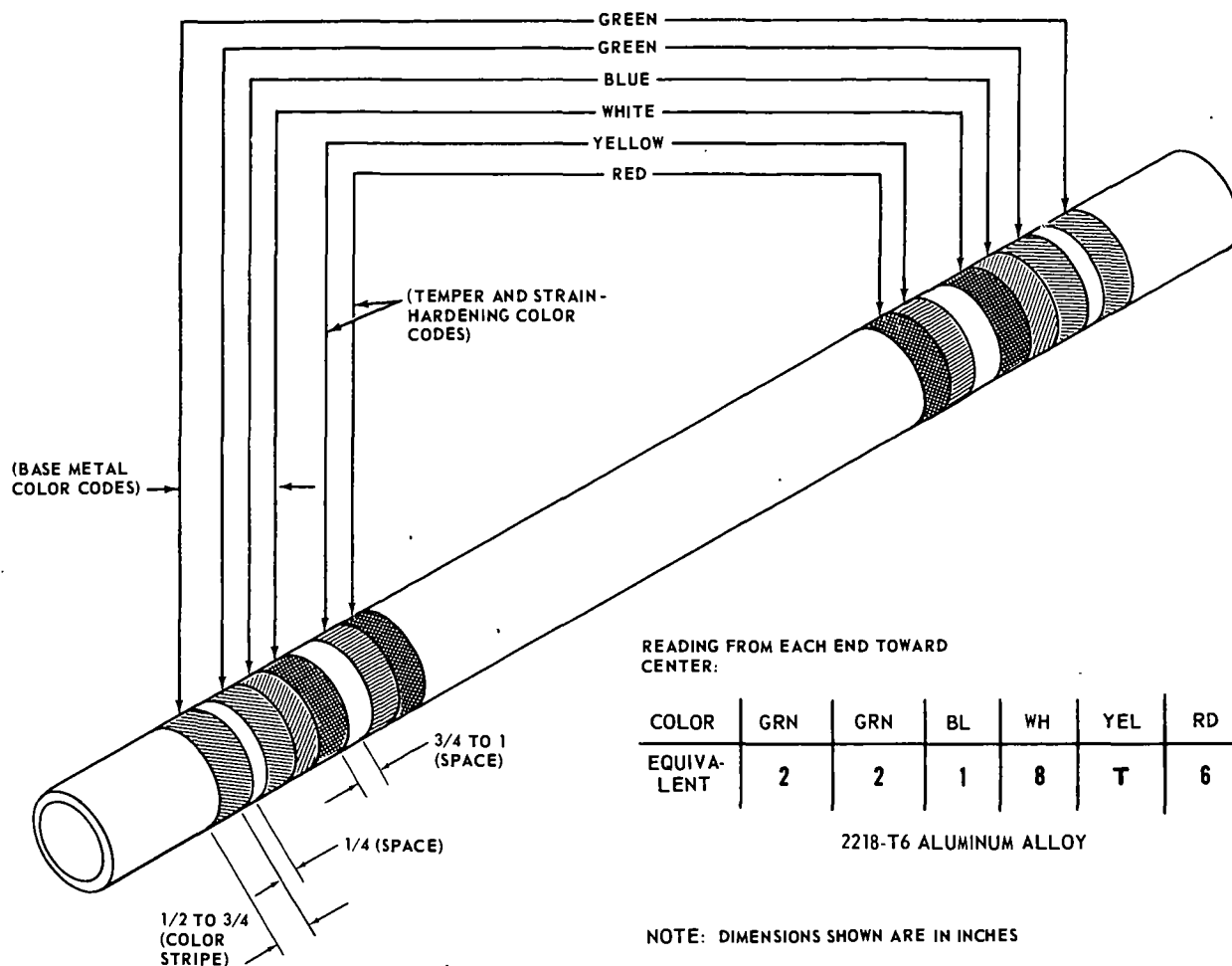


Figure 21. Example of color marking.

Table 12. Types of Aluminum Alloys

SHEET AND PLATE	
Commercial designation	Conditions and types available
1100	O (Annealed) H12 ($\frac{1}{4}$ -Hard) H14 ($\frac{1}{2}$ -Hard) H16 ($\frac{3}{4}$ -Hard) H18 (Hard) H22 ($\frac{1}{4}$ -Hard partially annealed) H24 ($\frac{1}{2}$ -Hard partially annealed) H26 ($\frac{3}{4}$ -Hard partially annealed) H28 (Hard partially annealed) H112 (As rolled) F (As fabricated)
3003	Same as 1100
Alclad 2014	O (Annealed) T3 T4

7075, and Alclad 7075. Cast and forging alloys can also be heat-treated. Wrought alloys invariably show a greater response to heat-treatment than do cast or forging alloys. The nonheat-treatable alloys commonly used are 1100, 3003, 5052, and 5056. For these the harder tempers are produced by cold working. Aluminum alloys may be given either a solution heat-treatment or a precipitation heat-treatment. Certain alloys develop their full strength from the solution heat-treatment alone, while others require both treatments to develop the desired physical properties.

(a) *Solution heat-treatment.* The solution heat-treatment of aluminum alloys consists of heating the metals to the highest temperature that can be used without danger of melting the metals, and holding them at that temperature long enough to produce the solid solution of the hardening constituents in the alloy. The term *solution* here refers to a solid homogeneously dispersed or mixed in another solid. After the holding period (soaking), the alloys are rapidly quenched to retain the produced solid solution. Aluminum alloys 2017 and 2024 develop their full properties when this treatment is followed by aging for about 4 days at room temperature. Age-hardening, which occurs completely in 2017 and 2024 materials at ordinary room temperatures in 4 days, is 90 to 98 percent complete after 24 hours. These alloys should be formed or otherwise worked within 1 hour after the solution heat-treatment so that the material may be worked easily without danger of cracking. The aging of 2017 and 2024 alloys may be retarded if the material is kept below a tempera-

ture of 32°F. (0°C.). Heat-treating clad sheet may be done in salt baths and air chamber furnaces. The molten salt bath has the advantage of bringing the metal to the proper temperature in a shorter time than does the air furnace. Various alloys have definite heat-treatment ranges at which the maximum improvement in mechanical properties can be accomplished. The temperatures specified in table 13 have given satisfactory results in the heat-treatment of wrought aluminum alloy products. The suggested length of time that each of the various alloy products should be held within the heat-treatment temperature range, after the coldest part of the range (soaking time), is given in table 14. When a charge includes parts of various thicknesses, whether in an assembly, in separate pieces, or as overlapping members, the soaking period is determined by the maximum thickness of the load. Because of this, charges of clad alloys involving different thicknesses of material should be avoided as much as possible to prevent diffusion of the alloy through the clad coating of the thinner parts. Heat-treating 2017 and 2024 alloys at the same time is not satisfactory, although the soaking temperature ranges for the two alloys touch at 930°F. (499°C.). After the charge has been soaked for the proper length of time at the proper temperature, it should be quenched by immersion in one of several media, such as water, oil, or air. The quenching tanks used for bare and clad 2017, 2024, and 7075 sheet, strip, and other thin-sectioned products must contain a sufficient volume of water, so that the average temperature rise of the water after quenching a normal load does not exceed 20°F.

Table 12. *Types of Aluminum Alloys—Continued*

Commercial designation	Conditions and types available
	T42 T6 T451 T651 F
2024	O T3 T36 T4 T42 T6 T81 T86 T351 T851 F
Alclad 2024	O T3

Table 12. Types of Aluminum Alloys—Continued

Commercial designation	Conditions and types available
	T36 T4 T42 T6 T81 T86 T351 F
5052	Same as 1100
6061	O T4 T6 T451 T651 F
7075	O T6 T651 F
Alclad 7075	O T6 T651 F

BARS, RODS, AND SHAPES

Commercial designation	Type	Conditions and types available
1100	Rolled, drawn, or cold finished	O (Annealed) H12 ($\frac{1}{4}$ -Hard) H14 ($\frac{1}{2}$ -Hard) H16 ($\frac{3}{4}$ -Hard) H18 (Hard) H112 (As fabricated)
3003	Extruded	O (Annealed) H112 (As extruded) H (As fabricated)
3003	Rolled, drawn, or cold finished	O (Annealed) H12 ($\frac{1}{4}$ -Hard) H14 ($\frac{1}{2}$ -Hard) H16 ($\frac{3}{4}$ -Hard) H18 (Hard) F (As fabricated)
2001	Free machining	T3 T8
2014	Extruded	O T4 T42 T4510 T4511 T62 T6510 T6511

Commercial designation	Type	Conditions and types available
2014	Rolled, drawn, or cold finished	O T4 T451 T6 T651
2017	Rolled or drawn	O T4 T451
2024	Extruded	O T351 T4 T42 T8510 T8511 T81
2024	Rolled, drawn, or cold finished	O T351 T4 T6 T851
5052	Rolled, drawn, or cold finished	O H32 ($\frac{1}{4}$ -Hard) H34 ($\frac{1}{2}$ -Hard) H36 ($\frac{3}{4}$ -Hard) H38 (Hard) F
6061 and 6062	Extruded	O T4 T6
6061	Rolled, drawn, or cold finished	O T4 T451 T6 T651 T6511
7075	Extruded	O T6 T6510
7075	Rolled, drawn, or cold finished	O T6

CASTINGS

Commercial designation	Composition	Alloy	Temper
Sand castings	2	43	F
	3	356	T6
	3	356	T51
	3	356	T4
	4	195	T4
	4	195	T6

Table 12. Types of Aluminum Alloys—Continued

Commercial designation	Composition	Alloy	Temper
	4	195	T62
	4	195	T7
	5	214	F
	6	142	T21
	6	142	T571
	7	122	T2
	5	122	T61
	8	108	F
	8	108	T55
	9	113	F
	10	355	T6
	10	355	T51
	10	355	T7
	10	355	T71
	16	220	T4
	17	40E	T5
	17	40E	T5
	18	Allcast	F
	18	Allcast	T6
	319	319	F
	319	319	T5
	319	319	T6
	20	Red X-8	F
	20	Red X-8	T6
	21	T1	T5
Permanent and semi-permanent mold castings	1	113	F
	2	122	T551, T65
	3	142	T571, T61
	4	B195	T4, T6, T7
	5	A108	F
	6	355	T6, T51, T62, T71
	7	43	F
	8	356	T6, T7
	9	A132	T551, T65
	10	B132	T5, T6
	11	319	F, T6
	12		T5
	13		T5
	14		T5, T7
	15	750	T5
	16	A214	F
	17	333	F, T5, T6, T7
	18	357	T6
	19	A750	T5
	20	B750	T5
Die castings	1	13	
	2	A13	
	3	43	
	7	218	
	10	A380	
	11	380	
	12	360	
	12A	A360 SC114A	

Commercial designation	Composition	Alloy	Temper
Forgings heat-treated		2014	T4
		2017	T4
		2018	T6
		2025	T6
		2218	T61
		2618	T61
		4032	T6
		6061	T6
		6066	T6
		6151	T6
		7075	T6
		7076	T61
		7079	T6

SEAMLESS TUBING, ROUND, SQUARE, RECTANGULAR, AND OTHER SHAPES

Commercial designation	Conditions and types available
1100	O (Annealed) H12 (¼-Hard) H14 (½-Hard) H16 (¾-Hard) H18 (Hard) F (As fabricated)
2024	O T3 T4
3003	O H12 (¼-Hard) H14 (½-Hard) H16 (¾-Hard) H18 (Hard)
5052	O (Annealed) H32 (¼-Hard) H34 (½-Hard) H36 (¾-Hard) H38 (Hard) F (As fabricated)
6061 and 6062	O T4 T6
6061 and 6062 (Hydraulic Quality)	T4 T6

Table 13. Suggested Heat-Treating (Soaking) Temperature for Aluminum Alloys

Wrought alloys (excluding forgings)	Temperature (°F.)		Temperature (°C.)	
	From	To	From	To
2014, 2017, 2117	930	950	499	510
2024, Alclad 2024	910	930	488	499
6053, 6061	960	980	516	527
7075, Alclad 7075 (sheet)	860	930	460	499
7075 (Extruded shapes)	860	880	460	471

Table 14. Soaking Time for Solution Heat-treatment of Wrought Aluminum Alloys (Excluding Forgings)

Alloy	Time required for given thickness ^a (minutes)			
	0.032 in. or less	Over 0.032 to 0.125 in.	Over 0.125 to 0.250 in.	Over 0.250 in.
2014	----	----	30	60
2117	20	20	30	60
2017	20	20	30	60
2024	30	30	40	60
Alclad 2024 ^b	20	30	40	60
6053	20	30	40	60
6061	20	30	40	60
7075	25	30	40	60
Alclad 7075 ^b	20	30	40	60

^a Measured from the time at which the load reaches the minimum heat-treating temperature.

^b For clad material, the time during which the material is held at the given temperature shall be a minimum compatible with the resultant specified physical properties in order to prevent excessive diffusion. Particular attention shall be given to material 0.064 in thick and greater which has a 2½ percent approximate thickness of cladding.

(11°C.). Greater temperature rises are, of necessity, permitted for heavily sectioned products, but the temperature rise must be always kept to the minimum practicable for the particular product. Wrought alloy parts (except forgings) in 2017, 2117, 2024, and 7075 must be quenched by total immersion in water at a temperature not higher than 100°F. (38°C.) before the charge enters the water. For 2017, 2024, and 7075 material, a rapid quench is necessary to give the resulting product maximum resistance to corrosion. If the material is quenched slowly, it will show an excessive reduction of physical properties when exposed to corrosive conditions. For clad 2024 and 7075 material, a rapid quench is necessary in order to develop maximum resistance to corrosion attack. However, a solution heat-treated clad sheet, even when air-blast quenched, generally shows lower losses in properties when exposed to corrosive conditions than does an uncoated sheet which has been cold-water quenched. The method of quenching any individual part should produce the most uniform

cooling possible. For the most part, distortion of heat-treated parts results from nonuniform cooling during quenching. This distortion may vary with the position in which a part enters the quenching bath. Tests on hat-shaped sections quenched flanges-down, flanges-up, and vertically have shown that distortion can vary from an angular twist of 45° for the flange-down position to no angular distortion for the vertical position.

Note. Place the part in the quenching solution edgewise or in such manner that any tendency to float is minimized.

(b) *Precipitation heat-treatment (artificial aging).* Precipitation heat-treatment is utilized to artificially age material which has previously been solution heat-treated. Certain aluminum alloys require this treatment to produce the fully heat-treated condition, including the complete development of their mechanical properties. In precipitation heat-treatment, the alloys are soaked at specified temperatures, well below the annealing temperatures, for the length of time required to develop the specified properties. The aging times and temperatures are shown in table 15. During precipitation heat-

Table 15. Aging Temperature for Aluminum Alloys

Wrought alloy ^a	Aging time (hr)	Aging temperature (°F.)		Aging temperature (°C.)	
		From	To	From	To
2017, 2117, 2024	96	b	b	b	b
Alclad 2024	8	345	355	174	179
2014	5	355	365	179	185
6053, 6061	12 to 20	315	325	157	163
7075 ^c	6 to 10	345	355	174	179
Alclad 7075	24	245	255	118	124

^a Excluding forgings.

^b Room temperature

^c Unless the aging treatment is begun within 2 hours after quenching, the material should be allowed to age-harden at room temperature for not less than 2 days before it is subjected to the aging treatment.

treatment, a portion of the hardening constituents in solid solution precipitates or drops out of the solution and forms particles which are distributed throughout the alloy. These particles, although submicroscopic, are effective in increasing the strength of the alloy. This precipitation results in an increase in yield strength, an increase in tensile strength, and a decrease in the elongation of the alloys.

(2) *Annealing.* Annealing can be considered a heat-treating process to remove the strain-hardening that results from cold working aluminum or to remove the effects of heat-treatment (to soften heat-treated material). Annealing consists of bringing the alloys to a definite

elevated temperature, soaking them at this temperature for a length of time depending on the mass of the metal, and then cooling them in still air. There are various applications and degrees of this process. Annealing is best carried out in an air furnace. A salt bath consisting of equal parts of sodium nitrate and potassium nitrate may be used, as such a salt mixture is molten at a temperature below the annealing temperatures of the material being annealed.

(a) *Anneal of work-hardened aluminum.* The annealing of material (other than 7075) which was initially in the soft or annealed condition but which has been strain-hardened by cold working is accomplished by heating the metal to a temperature of $660^{\circ} \pm 10^{\circ}\text{F.}$ ($349^{\circ} \pm 6^{\circ}\text{C.}$). It is necessary to hold the material at this temperature only long enough to make certain that the whole load has been brought within the specified range. If the metal is heated appreciably above 670°F. (354°C.), there will be a partial solution of the hardening constituents and the alloy will age-harden when standing at room temperature unless it is cooled very slowly. If the temperature is not raised to 650°F. (343°C.), the softening process may not be complete. If the annealing temperature applied to work-hardened material is kept within the proper limits, the rate of cooling is not particularly important. A rapid quench, however, should be avoided, as it sets up quenching strains. A slow cooling is desirable in the event any part of the load has been heated above the recommended temperature.

(b) *Partial anneal of heat-treated aluminum.* If aluminum has been heat-treated and a partial annealing of it is acceptable because the material is not to undergo subsequent severe forming operation, the procedure described in (a) above is satisfactory. It removes the effects of heat-treatment in a considerable measure.

(c) *Full anneal of heat-treated aluminum.* The complete removal of the effects of heat-treatment is accomplished by a full anneal of the heat-treated aluminum alloy. The alloys (except 7075) are heated to a temperature of 750° to 800°F. (399° to 427°C.) and held at this temperature long enough to insure that all parts of the load are at the correct temperature for at least 1 hour. Cooling the alloys after they are fully annealed in controlled at a rate not greater than 50°F. (27.8°C.) per hour until the temperature has dropped to 500°F. (260°C.). The rate of cooling below this point is unimportant. Full anneal for 7075 material, whether in the work-hardened condition or the heat-treated condition, is accomplished by heating the material to a temperature of 775° to 850°F.

(412° to 454°C.) (the higher temperature required for the material having the smaller amount of cold work), soaking the material at this temperature for 2 hours, and cooling it to room temperature.

23. Magnesium Alloys

a. *Description.* Magnesium is the world's lightest structural metal. Aluminum is 1.5 times as heavy, titanium is 2.5 times as heavy, steel is 4 times as heavy, and copper and nickel alloys are 5 times as heavy. Magnesium is probably more widely distributed in nature than any other metal. It can be obtained from ores such as dolomite and magnesite from underground brines and waste liquors of potash manufacture and from sea water. Magnesium is alloyed with small amounts of certain other metals including aluminum, manganese zinc, zirconium, thorium, and others, to obtain the strong, lightweight alloys needed for structural purposes. The recently developed thorium containing alloys are suitable for use at temperatures in excess of 700°F. (371°C.). Table 16 lists the magnesium alloys commonly used in aircraft construction and indicates the forms in which they are supplied. As shown in the table, magnesium alloys are used in both the cast and wrought forms. The cast alloys are used in making landing wheels, engine sections, accessory housings, sumps, and small airframe castings. The wrought alloys are used as extrusions, sheet, and plate.

b. *Identification of Magnesium Alloys.*

(1) *Identification method.* Magnesium alloys are identified by a standard system of alloy designation, adopted in 1948 by the American Society for Testing Metals (ASTM). As an example of how the system works, consider the magnesium alloy AZ92A-T4. The first part of the designation (AZ) signifies that aluminum and zinc are the two principal alloying elements. The second part of the designation (92) means aluminum and zinc are present in rounded-off percentages of 9 and 2 percent. The third part (A) indicates that this is the first alloy standardized with 9 percent aluminum and 2 percent zinc as the principal alloys. The fourth part (-T4) notes that the alloy is in the solution heat-treated condition. Table 17 gives a complete breakdown of the ASTM designation system.

(2) *Identification test.* If for any reason identification markings are not on material, use a spot test to distinguish magnesium from aluminum. Clean unknown alloy with a file, removing all paint or other surface coating to expose base metal. Place a drop of 1/2 to 1-percent solution of silver nitrate on cleared surface. The metal is magnesium when surface tested turns

black. When no reaction occurs, metal is probably aluminum.

Note. Cadmium and zinc also react to silver nitrate, but these metals are in thin coatings and should be removed by filing previously performed.

c. Working Practices. The machining characteristics of magnesium alloys are excellent. Usually the maximum speeds of machine tools can be used with heavy cuts and high feed rates.

Table 16. Commonly Used Magnesium Alloys

ALLOY (ASTM NO.)	NOMINAL COMPOSITION (PERCENT)						
	ALUMINUM	MANGANESE	ZINC	ZIRCONIUM	RARE EARTHS	THORIUM	MAGNESIUM
SAND AND PERMANENT MOLD CASTINGS							
AZ92A	9.0	0.15	2.0	....	....	...	Balance
AZ63A	6.0	0.25	3.0	....	....	....	Balance
EK41A	...	....	....	0.6	4.0	....	Balance
EZ33A	.	....	2.7	0.7	3.0	....	Balance
HK31A	..	....	....	0.7	....	3.0	Balance
DIE CASTINGS							
AZ91A	9.0	0.20	0.6	....	....	.	Balance
EXTRUSIONS							
AZ31B	3.0	0.45	1.0	....	....	....	Balance
AZ61A	6.5	0.30	1.0	....	...	....	Balance
M1A	..	1.50	....	....	....	....	Balance
AZ80A	8.5	0.25	0.5	....	....	....	Balance
SHEET AND PLATE							
AZ31B	3.0	0.45	1.0	....	....	....	Balance
HK31A	...	....	....	0.7	.	3.0	Balance

Table 17. Standard Alloy Designation System for Magnesium (ASTM)

First part	Second part	Third part	Fourth part
Indicates the two principal alloying elements.	Indicates the amounts of the two principal alloying elements.	Distinguishes between different alloys with the same rounded-off percentages of the two principal alloying elements.	Indicates condition and properties.
Consists of two code letters representing the two main alloying elements arranged in order of decreasing percentage.	Consists of two whole numbers corresponding to rounded-off percentages of the two main alloying elements and arranged in same order as the alloy designations in the first part.	Consists of a letter of the alphabet assigned in order as compositions become standard.	Consists of a letter followed by a number (separated from the third part by a dash).
A—Aluminum E—Rare earth H—Thorium K—Zirconium M—Manganese Z—Zinc	Whole numbers.	Letters of alphabet except I and O.	F—As fabricated. O—Annealed. H24—Strain hardened and partially annealed. T4—Solution heat treated. T5—Artificially aged only. T6—Solution heat treated and artificially aged.

Power requirements for magnesium alloys are about one-sixth of those for mild steel. An excellent surface finish can be produced, and in most cases grinding is not essential. Standard machine operations can be performed to tolerances of a few ten-thousandths. There is no tendency of the metal to tear or drag. Magnesium alloy sheets can be worked in much the same methods as other sheet metal. Sheets can be sheared in much the same way as other metals except that a rough, flaky fracture is produced on sheets thicker than about 0.064 inch. A better edge will result on a sheet over 0.064 inch thick if it is sheared hot. Magnesium alloys tend to crack after being cold worked. For this reason, wrought products made of these alloys are generally produced by hot working, rolling, extruding, or forging. The temperatures at which the wrought alloys are formed vary from 450° to 700°F. (232° to 371°C.). Parts formed at temperatures near the lower end of this range are stronger than those formed at higher temperatures. This is due to an annealing effect, which varies with the temperature at which the forming is accomplished. Magnesium alloys are quite resistant to normal atmospheric corrosion even when unprotected. When painted and given proper treatment, these alloys will resist the corrosive effects of salt air. They should not be used for parts in continuous contact with salt water. Magnesium alloys suffer only visible surface corrosion and are not subject to intercrystalline corrosion. Unpainted engine castings that are oily or greasy most of the time do not suffer corrosion. Powdering or roughening of the surface indicates corrosion. Magnesium alloys must be insulated from contact with other metals to avoid electrolytic corrosion.

24. Titanium and Titanium Alloys

a. Description. Titanium was discovered shortly after the Revolutionary War by an English priest named Gregor. A crude separation of titanium ore was accomplished in 1825. In 1906 a sufficient amount of pure titanium was isolated in metallic form to permit a study. Following this study, in 1932, an extraction process was developed which became the first commercial method for producing titanium. The United States Bureau of Mines began making titanium sponge in 1946, and 4 years later the melting process began. The use of titanium is widespread. It is used in many commercial enterprises and is in constant demand for such items as pumps, screens, and other tools and fixtures where corrosion attack is prevalent. In aircraft construction and repair, titanium is used for fuselage skins, engine shrouds, firewalls, longerons,

frames, fittings, air ducts, and fasteners.

(1) *Crystal structure.* In the solid state, each metal has a prevalent and characteristic formation of its atoms. The arrangement of this structure has definite influence on the characteristics of the metal. Alloying can alter structures or produce a combination of structures. The A-B-C classification of titanium alloys was established to provide a convenient and simple means of describing all titanium alloys. Titanium and titanium alloys possess three basic types of crystals: A (alpha), B (beta), and C (combined alpha and beta). Their characteristics are—

A (alpha)—All-around performance; good weldability; tough and strong both cold and hot, and resistant to oxidation; bendability poor.

B (beta)—Bendability; excellent bend ductility; strong, both cold and hot, but vulnerable to contamination; big consumer of strategic alloys.

C (combined alpha and beta for compromise performances)—Strong when cold and warm, but weak when hot; good bendability; moderate contamination resistance; excellent forgeability.

(2) *Characteristics.* Titanium is a metal that is between aluminum and stainless steel in terms of modulus of elasticity, density, and elevated temperature strength. It has a melting point of 2730° to 3155°F. (1499° to 1735°C.), low thermal conductivity, and low coefficient of expansion. It is light, strong, and resistant to stress-corrosion cracking in marine atmosphere. Titanium becomes softer as the degree of purity is increased. It is not practical to distinguish between the various grades of commercially pure or unalloyed titanium by chemical analysis. Therefore, the grades are determined by mechanical properties. Titanium is approximately 60 percent heavier than aluminum and about 50 percent lighter than stainless steel. It is useful from a strength standpoint up to about 1000°F. (538°C.). If it is subjected to temperatures of 1000°F. (538°C.) or more for a long period of time, it becomes very brittle. This metal is non-magnetic and has an electrical resistance comparable to that of stainless steel. Some of the base alloys of titanium are quite hard. Heat-treating and alloying do not develop the hardness of titanium to the high levels of some of the heat-treated alloys of steel. It was only recently that a heat-treatable titanium alloy was developed. Prior to the development of this alloy, heating and rolling was the only method of forming that could be accomplished. However, it is possible to form the new alloy in the soft

condition and heat-treat it for hardness. In view of the high melting point of titanium, high temperature properties are disappointing. The ultimate yield strength of titanium drops rapidly above 800°F. (427°C.). The absorption of oxygen and nitrogen from the air at temperatures above 1000°F. (538°C.) makes the metal so brittle on long exposure that it soon becomes worthless. However, titanium does have some merit for short-time exposure up to 3000°F. (1649°C.) where strength is not important. Aircraft firewalls demand this requirement. Iron, molybdenum, and chromium are used to stabilize titanium and produce alloys which will quench-harden and age-harden. The addition of these metals also adds ductility. The fatigue resistance of titanium is greater than that of aluminum or steel. The peculiar characteristic of this metal is that it never reacts the same when forming sharp angles and bends. Titanium is very sensitive to stresses or strains. The corrosion-resistance of titanium deserves special mention. The mechanism involves the formation of a protective film of stable oxide or chemi-absorbed oxygen. Film is often produced by the presence of oxygen and oxidizing agents. Attack of some corrosive media is often inhibited by impurities and minor components of commercial solutions. Laboratory tests with acid and saline solutions show titanium polarizes readily. The net effect, in general, is to decrease current flow in galvanic and corrosion cells. Corrosion currents on the surface of titanium and metallic couples are naturally restricted. This partly accounts for good resistance to many chemicals; also, the material may be used with some metals with no harmful galvanic effect on either. Corrosion of titanium is uniform. There is little evidence of pitting or other serious forms of localized attack. Normally, it is not subject to stress corrosion, erosion corrosion, corrosion fatigue, intergranular corrosion, or galvanic corrosion.

b. Identification. Titanium is manufactured for commercial use in two basic compositions: commercially pure titanium and alloyed titanium. A-55 is an example of a commercially pure titanium. It has a yield strength of 55,000 to 80,000 psi and is a general-purpose grade for moderate to severe forming. It is sometimes used for nonstructural aircraft parts and for all types of corrosion-resisting applications, such as tubing. Type A-70 titanium is closely related to type A-55, but has a yield strength of 70,000 to 95,000 psi. It is used where higher strength is required, and it is specified for many moderately stressed aircraft parts. For many corrosion applications, it is used interchangeably with type A-55. Both type A-55 and type A-70

are weldable. One of the titanium base alloys which is widely used is designated as C-110M. It is widely used for primary structural members and aircraft skin in airframe applications, has 110,000 psi minimum yield strength, and contains 8 per cent manganese. Type A-110AT is a titanium alloy which contains 5 percent aluminum and 25 percent tin. It also has a minimum yield strength at elevated temperatures with the excellent welding characteristics inherent in alpha-type titanium alloys. Titanium, in appearance, is similar to stainless steel. One quick method used to identify titanium is the spark test. Titanium gives off a brilliant white trace ending in a brilliant white burst. Also, identification can be accomplished by moistening the titanium and drawing a line on a piece of glass. This will leave a dark line similar in appearance to a pencil mark. Titanium is non-magnetic. The various types of titanium alloy compositions are shown in table 18.

c. Working Practices.

(1) *Grinding.* Titanium and its alloys can be ground at about the same rate of speed as hardened high speed steels and die steels. Moderately light cuts are recommended; and periodic dressing is required to keep the wheel in proper condition, the frequency of dressing depending upon grinding conditions. Excessive wheel loading leads to poor grinding action with subsequent poor surface finish, high residual tensile stresses, and low grinding ratios. Wheel wear can occur in different ways with different results: by attrition, causing flat spots in individual grains; by grain fractures, which expose new and sharp cutting points and edges; and by bond fracture, which causes abrasive grains, individual or in clusters, to leave the wheel. These phenomena occur regardless of the material ground, and the relative amount of each contributing factor depends on grinding conditions and the material itself. Wear by attrition that is associated with titanium's chemical reaction toward abrasives becomes excessive only when titanium is ground improperly. Loading, a phenomena by which a metal being ground is deposited on or between the abrasive grains, or both, can occur whether the wheel is sharp or dull. Drilling will intensify the loading process, for as loading continues, the grinding action decreases until burnishing occurs. The grinding temperature rises, causing high residual stresses in the ground surface, and results generally in an unsatisfactory surface finish. Titanium can crack when ground under the same grinding conditions normally used for steels. Under proper grinding conditions for titanium, however, grinding cracks appear to be no longer

Table 18. Titanium and Titanium Alloys

SHEET AND STRIP—MILITARY SPECIFICATION MIL-T-9046			
Percent alloy	Class	Condition	Tensile strength (psi—min)
8Mn	1	Hot rolled, an-	120,000
6Al-4V	2	nealed, and	130,000
5Al-2.5 Sn	3	descaled	120,000
2 Fe-2Cr-2Mo	4		120,000
BARS, FORGINGS, AND FORGING STOCK—MILITARY SPECIFICATION MIL-T-9047			
Unalloyed	1	Hot worked,	80,000
5Al-2-½Sn	2	annealed and	115,000
3Al-5Cr	3	descaled	140,000
2Fe-2Cr-2Mo	4		130,000
6Al-4V	5		130,000
4Al-4Mn	6		140,000
5Al-1-½Fe-	7		145,000
1-½Cr-1-½MO			
Al-Aluminum	Mn-Manganese	V-Vanadium	
Cr-Chromium	Mo-Molybdenum		
Fe-Iron (Ferrum)	Sn-Tin (Stannum)		

the problem they were when alloys were not of present high quality and contained an excessive amount of hydrogen.

Also, when etching solutions that contain hydrofluoric acid in the presence of insufficient nitric acid are used to reveal cracks, they may cause cracks to form if sufficiently high tensile stresses are present initially in the surface. Grinding difficulties can be minimized by employing the proper type wheels at low wheel speed and feeds, and by flooding the grinding area with an inhibitor or purging type of cutting fluid. Grinding temperature must be low to keep stresses low. Dry grinding is not recommended. Instead, proper wheel speeds, frequent wheel dressing, and the use of appropriate wheels and grinding fluids are the minimum cutting requirements. Suitable operation sheets for the parts concerned should specify the data for these variables. High quality machine tools are important for good grinding conditions. Rigid setups of work and wheel are required to prevent vibrations which otherwise would contribute to surface damage. Supervise and control grinding operations very closely, adhering to recommended procedures without substitution. When grinding practice is questionable, quick checks can be made by dye or fluorescent penetrants to indicate possible surface cracking. Handle titanium parts with care. Avoid nicks and scratches on finished parts. (Some ground parts may have to be stress-relieved by heat-treating some time

before final inspection. One hour at 1000°F. (538°C.) is a common treatment.)

(2) *Drilling.* Titanium and its alloys may be difficult to drill unless certain procedures are followed. The galling action between titanium and tool materials, accentuated by high cutting temperatures, results in a rapid dulling of the cutting lips of the drill, which in turn produces poor cutting action and unsatisfactory holes. A sharp cutting drill produces tight curling chips and no drilling difficulty. As the drill becomes dull, the cutting temperatures rise and the metal begins to smear to the lips and margins of the bits. Chip flow becomes increasingly difficult as cutting temperatures rise. The appearance of feathered chips from the flutes indicates that the drill has become too dull for further use and should be replaced. The appearance of irregular and discolored chips indicates that the drill has failed. Drilling difficulties can be reduced by designing holes so they will be as shallow as possible; by using short, sharp drills of approved design; by using copious amounts of cutting fluids so they will penetrate to the chip-tool contact areas for maximum cooling; and by using low speeds and heavy feeds. When improper drilling methods are used, out-of-round, tapered, or smeared holes occur. To prevent or minimize these difficulties, use sharp, clean drills of recommended material, size, and geometry; operate under appropriate cutting procedures; and holes will be

produced of proper size and quality. Careful handling of titanium parts is essential. This means avoiding scratches and nicks on all titanium parts, both around the drill press and in transit.

(3) *Sawing.* Power hacksaws, band saws, and friction saws are used for sawing titanium and its alloys. Successful band sawing of AMS 4908 alloy is accomplished with a standard 1/2-inch wide blade having 10 teeth per inch and traveling at about 2500 feet per minute. Constant rate of feed of about 25 feet per minute is necessary. Water-soluble coolants are desirable. Friction sawing is readily accomplished, provided a positive feed is maintained and there is no interruption in the cut. A heavy burr is formed, proportional to the gage thickness, which must be removed. Sawed edges must be draw-filed or belt-sanded to remove the ragged edges before forming to prevent the possibility of subsequent cracking.

(4) *Shearing.* Shearing is successfully applied to titanium and its alloys provided dies are in perfect condition. Die life is relatively short, maintenance cost is relatively high, and sheared and blanked edges are not satisfactory without further hand-filing, machining, or belt-sanding to remove shear cracks. For gages up to about 0.040 inch, 0.010 inch removal is sufficient. For gages over 0.040 inch, 0.020 to 0.025 inch must be removed from the sheared edge. Particular attention must be paid to the sharpness of the shear knives; nicked knives should never be used. Straight shears are applicable in the conventional manner. Blanking and piercing dies (male and female) are comparable to those used on a 1/4-inch hard stainless steel. (Kirtsite blanking dies are not satisfactory.) Power contour shears, power roll shears, and unishears can be employed. Gages in excess of 0.080 inch require square shears for both alloy and commercially pure titanium.

(5) *Nibbling.* Nibbling is sometimes used for titanium alloys. Short tool life and high maintenance costs are penalties that must be accepted, however, for the convenience of the process.

(6) *Marking methods.* Commonly used marking methods are acceptable for titanium alloys, except those methods which physically damage the surface, such as impression stamps, scratch-awls, electric pencils, punch marks, etc. Good judgment is obviously required; for example, drilled holes for locating pins are universally punch marked prior to drilling. However, layout line intersections for locating of parts are not punched. Stencils are standard practice for denoting directional properties of sheets by

orienting stencil codes parallel to rolling directions. Stencils must be removed, however, prior to stress relieving, or damage occurs from etch effects during cleaning. With the aid of a few basic rules and proper equipment, titanium sheet can be formed on a commercial production basis. Many operations are carried out at room temperature. Best results are obtained by slow working, as the metal resists sudden movement. Use stretching, hydropressing, and draw pressing in preference to punch pressing and drop hammer work. After severe cold forming, stress relieving is desirable. Some parts are formed at room temperature, but others are more readily produced warm. If difficulty is encountered with cold forming, warming dies or work usually overcomes the trouble. Minimum heating helps, but better results are obtained in the 500° to 800°F. (260° to 427°C.) range.

(7) *Blanking by punch press.* The importance of the preformed blank in forming titanium alloys is generally recognized. The success of many forming operations depends to a large degree on the shape of the prepared blank and the accurate placement of the blank in relation to the die being used. Restraining forces can come from outside a trim line to cause tearing and wrinkling in the same manner that metal within the limits of the trim line affects the forming process. In general, minimum excess flash or trim is desirable from the standpoint of both scrap material and easy forming. Blanking commercially pure titanium sheet by punch press method produces results that are similar to those in blanking the common 1/4-hard stainless steels. Alloyed titaniums compare in most respects to 1/2-hard stainless steels. The force required to blank titanium is greater and the life of the blanking dies is shorter than those for stainless steels. It is important that dies blanking titanium be kept in excellent condition. Burring characteristics of titanium and of the common stainless steels are approximately equal in blanking operations. Blanking dies of various sizes and configurations have been used with gages of titanium sheet ranging from 0.016 to 0.125 inch. Holes, slots, and flat pattern developments can be blanked in the same manner and with nearly the same results and equipment as are obtained in blanking the common stainless steels. In blanking out details, production tools that are used for stainless steels can be used successfully in blanking both commercially pure and alloyed titanium. In many cases, the operator has no knowledge that titanium is being worked and suspects stainless steel is being worked. Holes of 1/2-inch diameter can be punched with a 2 1/2 tone Niagara Punch Press.

in the following materials: 0.016-inch RC-70, 0.025-inch RC-70, 0.040-inch RS-70, 0.063-inch T175A, and 0.125-inch RC-70. Alloyed titaniums up to 0.070 inch can be punched on this capacity press. This capacity press is also used successfully to punch 1-inch by 2-inch slots in 0.016-inch RC-70, 0.025-inch RC-70, 0.040-inch RC-70, 0.063 inch TI-75A, and 0.125-inch C-70. A 30-ton punch press is used to punch holes in 0.016-inch RC-70 and in 0.070-inch TI-75A. Tool life will be greatly shortened where such great force is required to do the job. A 100-ton press is required to punch 1/4-inch by 9/32-inch slots in 0.070-inch TI-75A and 0.032-inch 8Mn titanium. Several companies are experimenting with hot shearing and hot blanking in alloyed titanium to overcome the shear-cracking weakness in the material. To date, however, hot shearing or hot blanking is not being used in production. It is considered as only a temporary measure until material is improved. Blanking of titanium alloys in the hydropress has not been practical because of insufficient pressures in the machine. Neither have limitations been established for impact rubber blanking. It is quite apparent that, when using steel dies maintained in excellent condition, all blanking and piercing operations normally associated with 1/4-hard to 1/2-hard stainless steel will apply in the fabrication of titanium alloys. Sheet gages of titanium alloys below 0.050 inch thick have been punched and sheared with no evidence of shear cracking. Gages of 0.050-inch and 0.080-inch to 0.090-inch sometimes crack, and this seems to be a function of the maintenance of the shears and other problems associated with keeping the shears or the blanking dies in perfect condition. Gages above 0.080- or 0.090-inch are never sheared because of cracking which apparently takes place at room temperature under all circumstances. Experience gained in the industry indicates that, in general, sawing should be used in preference to shearing or blanking. In either case, however, whether a part is sawed, sheared, nibbled, or blanked out, it is necessary that the edge preparation be carried out so that approximately 0.025 inch of material is removed from the edge to make sure that no shear cracks or stress risers are present which could cause a crack or a tear in the part during forming operations.

(8) *Heat-treating.* Several of the commercial high-strength titanium alloys are quite responsive to heat-treatment, but only a few users have taken advantage of heat-treatment to gain strength. The major reasons are that the relatively unexplored quench hardening is still rather complex, and more conventional treatments

have given brittle products. A number of heat-treatments capable of enhancing alloy strength while maintaining adequate ductility are being investigated. The heat-treat potential of most titanium base alloys is based on the fact that the metal undergoes chemical transformation. It can exist as two different crystal structures; one transforming into the other, depending upon temperature. The broad outline of the mechanism of alloy transformation hardening includes formation of the higher temperature phase, beta, by heating, followed by sufficiently rapid cooling to retain some beta beyond the equilibrium point, and its subsequent transformation to the lower temperature phase, alpha. Titanium is heat-treated to relieve stresses set up during cold forming or machining. It is fully annealed after hot working, and it is thermal-hardened to improve strength, usually at some sacrifice in ductility.

25. Inconel

a. Description. Inconel is a nickel-chromium alloy containing about 77 percent nickel, 14 percent chromium, 7 percent iron, and small amounts of manganese, copper, and silicon. Inconel has great corrosion-resistance, retains its strength at high temperatures, and remains bright under exposure to a large variety of corrosives. The tensile strength of Inconel is very high, ranging from 80,000 to 100,000 psi in annealed form and from 165,000 to 185,000 psi in spring temper form. This metal responds to all standard joining methods. The ability of Inconel to resist the effects of combustion gases and to retain its strength and ductility at elevated temperatures (as high as 1600°F. (871°C.)) make this alloy valuable for aircraft exhaust stacks and manifolds, collector rings, cowling around exhaust pipes, firewalls, shrouding, and exhaust gas analyzer tubes. Because of its non-magnetic quality, Inconel is suitable for use around compasses.

b. Identification. Identification of Inconel by types is shown in table 19.

c. Working Practices. Inconel can be hardened only by cold working. (It cannot be hardened by heat-treatment.) Machining Inconel is difficult and must be done at low speeds with carefully treated and sharpened tools. Considerable heat is generated in machining. Inconel bends easily. Military specifications require that test pieces must withstand cold bending, any direction of the sheet, without cracking, through an angle of 180° on a diameter equal to the thickness of the test specimen. For shop work, it

Table 19. Identification of Inconel

SHEET, PLATE, AND STRIP			
Commercial designation	Current specification	Physical condition	Finish
ASTM B 168 or AMS 5540	MIL-N-6840	Sheet—Cold rolled and annealed Plate—Hot rolled and annealed Strip—Cold rolled and annealed or spring temper	(1) Sodium hydride descaled (2) Acid pickled (3) Controlled atmosphere an- nealed (0.125 inch and less in thickness) (4) Cold rolled (as rolled)
BARS, FORGINGS, AND RODS			
ASTM B 166	MIL-N-6710	A (Cold drawn and annealed) B (Cold drawn) C (Hot rolled) D (Forgings, hot finished) E (Forgings, hot finished and an- nealed) F (Hot rolled and annealed) G (Forging quality, for subse- quent hot manipulation)	(1) Pickled (2) As drawn (3) As rolled or as forged (4) As annealed (5) Rough ground or turned
AMS 5667 or AMS 5668	MIL-N-8550	A (Hot finished; rolled, forged, or extruded) B (Forging quality, for subse- quent hot manipulation) C (Solution treated) D (Solution treated and high- temperature aged) E (Fully heat-treated; solution treated, high temperature aged, and aged)	(1) Rough centerless ground (2) Rough turned (3) As hot finished
TUBING			
Commercial designation	Current specification	Type	Condition available
ASTM B 167 or AMS 5580	MIL-T-7840	I. Seamless II. Welded and drawn	Cold drawn, annealed, and pickled

would be advisable to call for bend radii equal to one thickness of the material. Inconel welds readily, rendering a strong, sound, ductile weld which resists corrosion. Welding may be done by electric arc, electric spark, seam (resistance welding), or with the oxyacetylene flame. Welded joints in the annealed material develop the strength of the base metal. As evidence of its ductility, a welded sheet may be bent flat on itself, at right angles to the weld, or along the welded seam, without cracking the weld.

26. Monel

a. Description. Monel, the leading high-nickel alloy, combines the properties of high-strength and excellent corrosion-resistance. This metal consists of 68 percent nickel, 29 percent copper,

1.5 percent iron, and 1 percent manganese. It cannot be hardened by heat-treatment, responding only to cold working. Monel shows good strength at high temperatures.

b. Identification. Identification of Monel by types is shown in table 20.

c. Working Practices. Monel is adaptable to casting and hot or cold working, can be successfully welded, and has properties similar to those of steel. When forged and annealed, it has a tensile strength of 80,000 psi which, by means of cold working, may be increased to 125,000 psi, thus entitling Monel to classification among the tough alloys. Because of its corrosion-resistance, it is substituted for steel where such resistance is of primary consideration. Monel has been successfully used for gears and chains, for

operating retractable landing gears, and for structural parts which are subject to corrosion. In aircraft construction, Monel has been used for parts demanding both strength and high resistance to corrosion, such as exhaust manifolds and carburetor needle valves and sleeves.

27. Copper and Copper Alloys

a. Description. Copper is one of the most widely distributed metals. It is the only reddish-colored metal and is second only to silver in electrical conductivity. Its use as a structural material is limited because of its great weight. However, some of its outstanding characteristics, such as its high electrical and heat conductivity, in many cases overbalance the weight factor. Because it is very malleable and ductile, copper is ideal for making wire. It is corroded by salt water but is not affected by fresh water. The ultimate tensile strength of copper varies greatly. For cast copper, the tensile strength is about 25,000 psi; and when cold rolled or cold drawn, its tensile strength increases to range from 40,000 to 67,000 psi. In aircraft, copper is used primarily in the electrical system and for instrument tubing and bonding. In the manufacture of tubing, the copper must be at least 99.9 percent pure. Standard requirements for aircraft fuel, oil, and water lines call for sizes ranging from 1/8-inch to 1 1/8-inch outside diameter. A wall thickness of 35/1000 inch is used for tubing with diameters less than 5/8 inch, and a thickness of 49/1000 inch for larger diameters. Copper is used in the pure form and is alloyed with various other elements. The most common of the copperbase alloys are brass and bronze. In brass, the chief alloying element is zinc, while in bronze the principal alloying element is tin. Other copper-base alloys are beryllium copper and copper silicon.

b. Identification. Since the use of copper and copper alloys in repair of aircraft structures is limited, identification by types is not included. Refer to Military Standard MIL-STD-455 for identification of copper and copper alloys.

c. Working Practices.

(1) *Brass.* Brass is a copper alloy containing zinc and small amounts of aluminum, iron, lead, manganese, magnesium, nickel, phosphorous, and tin. Brass with a zinc content of 30 to 35 percent is very ductile while that containing 45 percent has relatively high strength. Muntz metal is a brass composed of 60 percent copper and 40 percent zinc. It has excellent corrosion-resistant qualities in salt water. Its strength can be increased by heat-treatment. As cast, this metal has an ultimate tensile strength

of 50,000 psi, and it can be elongated 18 percent. It is used in making bolts and nuts, as well as parts that come in contact with salt water. Red brass, sometimes termed bronze because of its tin content, is used in fuel and oil line fittings. This metal has good casting and finishing properties and machines freely.

(2) *Bronzes.* Bronzes are copper alloys containing tin. The true bronzes have up to 25 percent tin, but those with less than 11 percent are most useful, especially for such items as tube fittings in aircraft. Among the copper alloys are the copper aluminum alloys, of which the aluminum bronzes rank very high in aircraft usage. They would find greater usefulness in structures if it were not for their strength-to-weight ratio as compared with alloy steels. Wrought aluminum bronzes are almost as strong and ductile as medium carbon steel, and they possess a high degree of resistance to corrosion by air, salt water, and chemicals. They are readily forged, hot or cold rolled, and many react to heat-treatment. These copper-base alloys contain up to 16 percent of aluminum (usually 5 to 11 percent), to which other metals such as iron, nickel, or manganese may be added. Aluminum bronzes have good tearing qualities, great strength, hardness, and resistance to both shock and fatigue. Because of these properties, they are used for diaphragms and gears, air pumps, condenser bolts, and slide liners. Aluminum bronzes are available in rods, bars, plates, sheets, strips, and forgings. Cast aluminum bronzes, using about 89 percent copper, 9 percent aluminum, and 2 percent of other elements, have high strength combined with ductility, and are resistant to corrosion, shock, and fatigue. Because of these properties, cast aluminum bronze is used in gun mounts, bearings, and pump parts. These alloys are useful in areas exposed to salt water and corrosive gases. Manganese bronze is an exceptionally high strength, tough, corrosion-resistant copper zinc alloy containing aluminum, manganese, iron, and, occasionally, nickel or tin. This metal can be formed, extruded, drawn, or rolled to any desired shape. In rod form, it is generally used for machined parts; otherwise, it is used in catapults, landing gears, and brackets. Silicon bronze is a more recent development composed of about 95 percent copper, 3 percent silicon, and 2 percent manganese, zinc, iron, tin, and aluminum. Although not a bronze in the true sense because of its small tin content, silicon bronze has high strength and great corrosion resistance and is used variably.

(3) *Beryllium copper.* Beryllium copper is one of the most successful of all the copper base

Table 20. Identification of Monel

SHEET, PLATE, AND STRIP			
Commercial designation	Current specification	Condition available	
ASTM B 127	QQ-N-281, Class A	Sheet—Hot or cold rolled Plate—Hot rolled Strip—Cold rolled	
	QQ-N-286, Class A or MIL-N-17506 Class A.	Sheet—Cold rolled and annealed. Strip—Cold rolled and annealed; cold rolled, annealed, and age-hardened; cold rolled, ½-hard; cold rolled, ½-hard, and age-hardened; cold rolled, full-hard; and cold rolled, full-hard, and age-hardened.	
BARS, FORGINGS, AND RODS			
ASTM B 164, Class A	QQ-N-281, Class A	Bars and Rods—Cold drawn, and hot rolled. Forgings—Hot finished, and high tensile.	
ASTM B 164, Class B	QQ-N-281, Class B	Bars and Rods—Cold drawn, and hot rolled.	
	QQ-N-286, Class A or MIL-N-17506, Class A.	Bar, Forgings, and Rods—Hot finished; hot finished and age-hardened; hot finished and annealed; and hot finished, annealed, and age-hardened. Bars and Rods—Cold drawn (As drawn); cold drawn and age-hardened; cold drawn and annealed; and cold drawn, annealed, and age-hardened.	
TUBING			
Commercial designation	Current specification	Type	Condition available
ASTM B 165	MIL-T-1368	I. Seamless II. Welded	Annealed; hard, stress-relieved; and stress-equalized.

alloys. It is a recently developed alloy containing about 97 percent copper, 2 percent beryllium, and sufficient nickel to increase the percentage of elongation. The most valuable feature of this metal is that the physical properties can be greatly stepped up by heat-treatment, the tensile strength rising from 70,000 psi in the annealed state to 200,000 psi in the heat-treated state. The resistance of beryllium copper to fatigue and wear makes it suitable for diaphragms, precision bearings and bushings, ball cages, and spring washers.

28. Hardness Testing of Metals

a. General. Hardness testing is a method of determining the results of heat-treatment as well as the state of a metal prior to heat-treatment.

Since hardness values can be tied in with tensile strength values and, in part, with wear resistance, hardness tests are an invaluable check of heat-treat control and of material properties. Hardness testing is accomplished by various types of instruments, all of which enable the operator to determine the ultimate strength of the material by checking its hardness.

b. Brinell Tester. The Brinell tester (fig. 22) uses a hardened spherical ball which is forced into the surface of the metal. The ball is 10 millimeters (0.3937 inch) in diameter. A pressure of 3,000 kilograms is used for ferrous metals and 500 kilograms for nonferrous metals. The pressure must be maintained at least 10 seconds for ferrous metals and at least 30

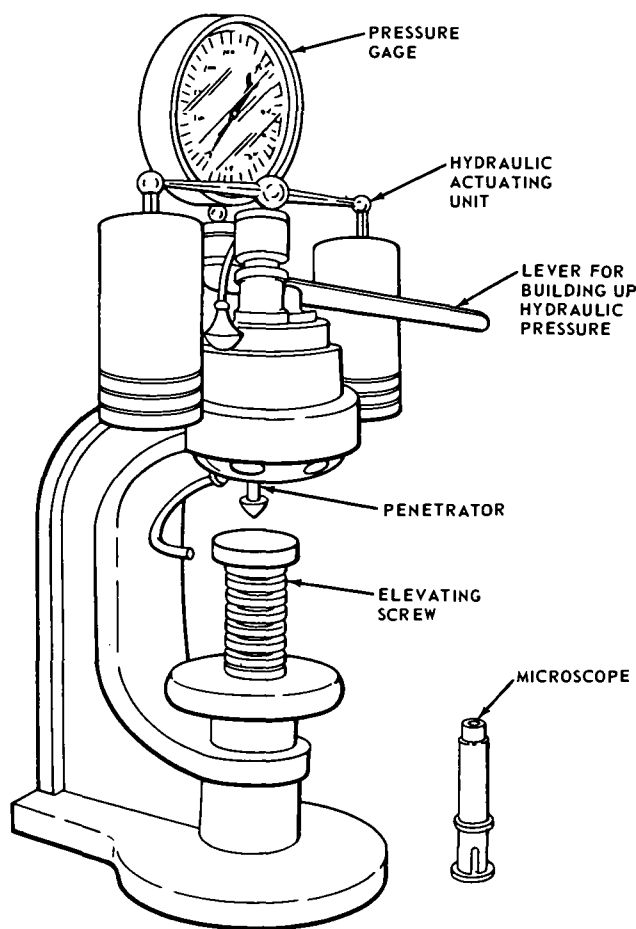


Figure 22. Brinell tester.

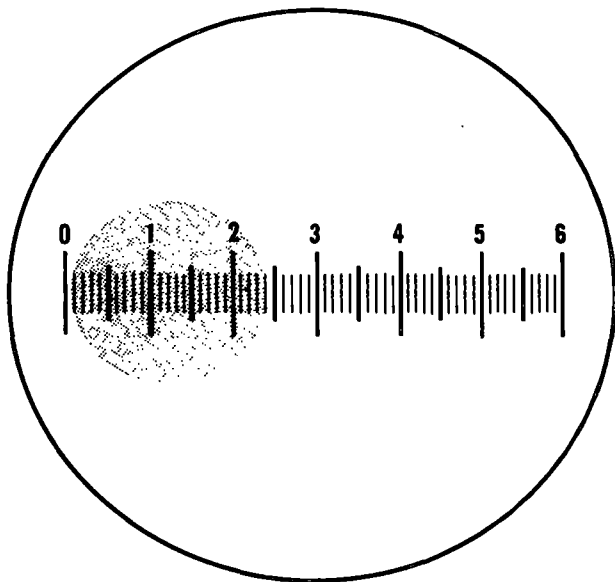


Figure 23. Impression viewed through microscope.

seconds for nonferrous metals. The load is applied by means of hydraulic pressure. The hydraulic pressure is built up by a hand pump or an electric motor, depending on the model of tester.

A pressure gage indicates the amount of pressure. There is a release mechanism for relieving the pressure after the test has been made, and a calibrated microscope is provided for measuring the diameter of the impression in millimeters. The machine has various shaped anvils for supporting the specimen and an elevating screw for bringing the specimen in contact with the ball penetrator. There are attachments for special tests. In order to determine the Brinell hardness number for a metal, the diameter of the impression is first measured, using the calibrated microscope furnished with the tester. Figure 23 illustrates an impression as seen through the microscope. After measuring the diameter of the impression, the measurement is converted into the Brinell hardness number on the conversion table furnished with the tester. A portion of the conversion table is shown in table 21.

c. *Rockwell Tester.* The Rockwell tester (fig. 24) measures the resistance to penetration as does the Brinell tester, but instead of measuring the diameter of the impression, the Rockwell tester measures the depth, and the hardness is indicated directly on a dial attached to the machine. The shallower the penetration, the higher is the hardness number. Two types of penetrators are used with the Rockwell tester, one being a diamond cone, the other a hardened steel ball. The load which forces the penetrator into the metal is called the major load and is measured in kilograms. The results of each penetrator and load combination are reported on separate scales, designated by letters. The penetrator, the major load and the scale vary with the kind of metal being tested. For hardened steels, the diamond penetrator is used, the major load is 150 kilograms, and the hardness is read on the C scale. When this reading is recorded, the letter C must precede the number indicated by the pointer. The C-scale setup is used for testing metals ranging in hardness from C-22 to the

Table 21. Portion of Conversion Table Furnished with Brinell Tester

Diameter of ball impression (MM)	Hardness number for load of KG	
2.0	158	945
2.05	150	899
2.10	143	856
2.15	136	817
2.20	130	780
2.25	124	745
2.30	119	712
2.35	114	682
2.40	109	653
2.45	100	627

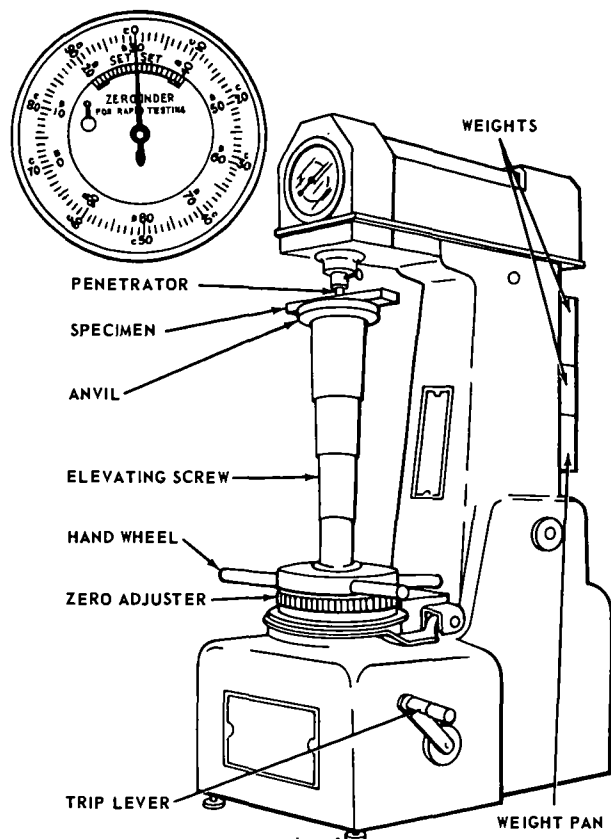


Figure 24. Rockwell tester.

hardest steel (usually about C-70). If the metal is softer than C-22, the B-scale setup is used. With this setup, the 1/16-inch ball is used as a penetrator, the major load is 100 kilograms, and the hardness is read on the B scale. In addition to the C and B scales, there are other setups for special testing. The scales, penetrators, major loads, and dial numbers to be read are listed in table 22. The dial numbers in the outer circle are black, and the inner numbers are red. The Rockwell tester is equipped with a weight pan, and two weights are supplied with the machine.

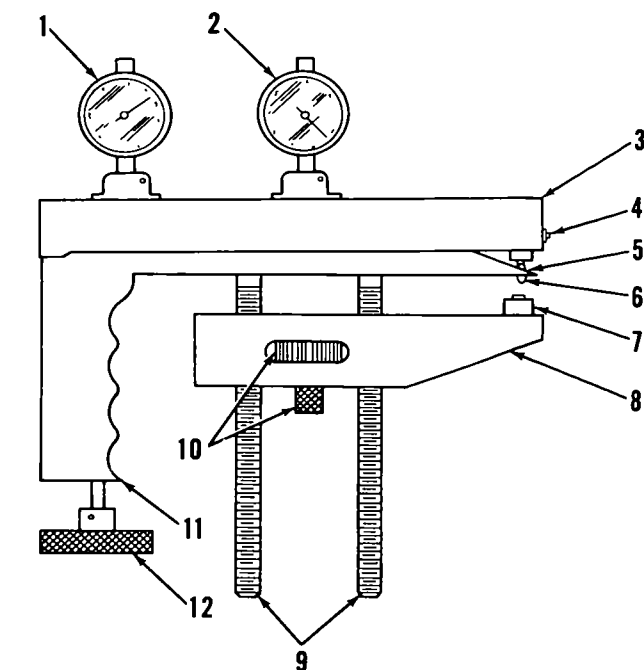
Table 22. Standard Rockwell Hardness Scales

Scale symbol	Penetrator	Major load (KG)	Dial number
A	Diamond	60	Black
B	1/16-inch ball	100	Red
C	Diamond	150	Black
D	Diamond	100	Black
E	1/8-inch ball	100	Red
F	1/16-inch ball	60	Red
G	1/16-inch ball	150	Red
H	1/8-inch ball	60	Red
K	1/8-inch ball	150	Red

One weight is marked in red; the other weight is marked in black. With no weight in the weight pan, the machine applies a major load of 60 kilograms. If the scale setup calls for a 100-kilogram load, the red weight is placed in the pan. For a 150-kilogram load, the black weight is added to the red weight. The black weight is always used in conjunction with the red weight; it is never used alone. Practically all testing is done with either the B-scale setup or the C-scale setup. For these scales the colors may be used as a guide in selecting the weight (or weights) and in reading the dial. For the B-scale test, use the red weight and read the red numbers. For the C-scale test, add the black weight and the red weight and read the black numbers. In setting up the Rockwell machine, use the diamond penetrator for testing materials which are known to be hard. If in doubt, try the diamond, as the steel ball may be deformed if used for testing hard materials. If the metal tests below C-22, then change to the steel ball. Use the steel ball for all soft materials (those testing less than B-100). Should an overlap occur at the top of the B scale and the bottom of the C scale, use the C-scale setup. Before the major load is applied, the test specimen must be securely locked in place to prevent slipping and to properly seat the anvil and penetrator. To do this, a load of 10 kilograms is applied before the lever is tripped. This preliminary load is called the minor load. The minor load is 10 kilograms regardless of the scale setup. When the machine is set up properly, it automatically applies the 10-kilogram load. The metal to be tested in the Rockwell tester must be ground smooth on two opposite sides and be free of scratches and foreign matter. The surface should be perpendicular to the axis of penetration, and the two opposite ground surfaces should be parallel. If the specimen is tapered, the amount of error will depend on the taper. A curved surface will also cause a slight error in the hardness test. The amount of error depends on the curvature, the smaller the radius of curvature, the greater the error. To eliminate such error, a small flat should be ground on the curved surface if possible.

d. Riehle Tester. The Riehle tester is a portable unit designed for making Rockwell tests comparable to the bench-type machine. The instrument is universal in its application, being readily adjustable to a wide range of sizes and shapes which would be difficult, or impossible, to test on a bench-type tester. Figure 25 shows the general arrangement and identifies the various components of the tester. It may be noted that the adjusting screws (9) and the penetration

indicator (2) are set back some distance from the penetrator end of the clamps. This makes it practicable to use the tester on either the outside or inside surface of tubing as well as on many other applications where the clearance above the penetrator or below the anvil is limited. The indicator brackets are arranged so that it is possible to turn the indicators to any angle for greater convenience in a specific application, or to facilitate its use by a left-handed operator. Adjustment of the lower clamp is made by the small knurled knob below the clamp. The larger diameter knob, extending through the slot in the side of the clamp, is used for actual clamping. Each Riehle tester is supplied with a diamond penetrator and a 1/16-inch ball penetrator. The ball penetrator should not be used on materials harder than B-100, nor on a load heavier than 100 kilograms. This is to avoid the danger of flattening the ball. The diamond penetrator, when used with a 150-kilogram load, may be used on materials from the hardest down to those giving a reading of C-20. When the expected hardness of a material is completely unknown to the operator, it is advisable to take



- | | |
|--------------------------|-------------------|
| 1 Load indicator | 7 Anvil |
| 2 Penetrator indicator | 8 Lower clamp |
| 3 Upper clamp | 9 Adjusting screw |
| 4 Penetrator clamp screw | 10 Adjusting knob |
| 5 Weigh bar | 11 Grip |
| 6 Penetrator | 12 Loading screw |

Figure 25. Riehle tester.

a preliminary reading on the A scale as a guide in selecting the proper scale to be used.

e. Barcol Tester. The Barcol tester (fig. 26) is a portable unit designed for testing aluminum

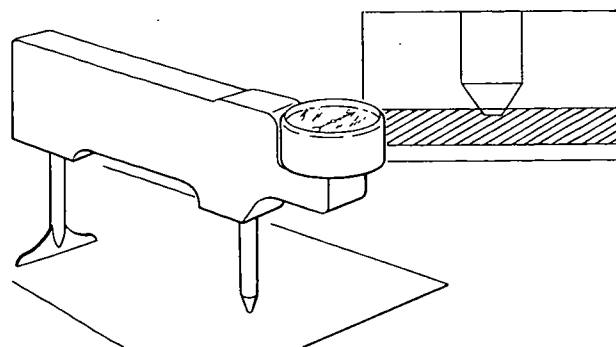


Figure 26. Barcol tester.

alloys, copper, brass, and other relatively soft materials. Approximate range of the tester is 25 to 100 Brinell. The unit can be used in any position and in any space that will allow for the operator's hand. The hardness is indicated on a dial conveniently divided into 100 graduations. The design of the Barcol tester is such that operating experience is not necessary. It is only necessary to exert a light pressure against the instrument to drive the spring-loaded indenter into the material to be tested. The hardness reading is instantly indicated on the dial. The harder the material, the higher is the Barcol number. To prevent damage to the point, avoid sliding or scraping when it is in contact with the material being tested. If the point should become damaged, it must be replaced with a new one. No attempt should be made to grind the point. Each tester is supplied with a test disk for checking the condition of the point. To check the point, press the instrument down on the test disk. When the downward pressure brings the end of the lower plunger guide against the surface of the disk, the indicator reading should be within the range shown on the test disk.

f. Scleroscope Tester. The Scleroscope tester (fig. 27) is another instrument used for examining the hardness of metals. This instrument does not test by indentation, but by rebound. It has a diamond-pointed ball that drops through a glass tube on the material to be tested. This tube is mounted with a graduated scale, and the rebound of the ball, or point, is caught by the eye at its peak and the corresponding graduation is then read. The instrument is also made with a direct-reading head which records the amount of rebound. A soft ball is provided for the examination of nonferrous material, and readings are taken from the same scale. When using the Scleroscope tester, the surface of the material must be clean and smooth. The glass must be perpendicular, and the material square with the glass. The hammer must not be dropped.

twice in the same place, as this may chip the diamond point and cause a false reading.

g. Webster Hand-Type Tester. The Webster hand-type tester (fig. 28) is a simple, pliers-type unit with an anvil on one jaw to support the work, and a series of inclined indenters of increasing crest area on the other jaw. This instrument is used for testing aluminum and aluminum alloys. When the indenters are forced into the metal by the action of the pliers, the number of indentations appearing on the surface in an indication of the hardness. An improved type of Webster instrument has a dial indicator that is read directly during the plier action, thus eliminating the necessity of looking at the part to count the indentations. Care must be taken in applying the indenter jaw normal

to (right angles to) the surface being tested, as any inclination or rotation will give inaccurate readings.

h. Shore Durometer. The Shore durometer (fig. 29) is used to determine the hardness of treated or molded rubber, plastics, and allied materials. Readings are taken directly from a reading head that is actuated by the upward travel of a pin of a given diameter, forced against the material to be tested. The pin is spring-mounted under a predetermined pressure; hence, its travel is governed by the degree of hardness of the material being tested. Until this pressure is reached by the resistance of the material, the needle will penetrate the material up to the point where the spring pressure is overcome.

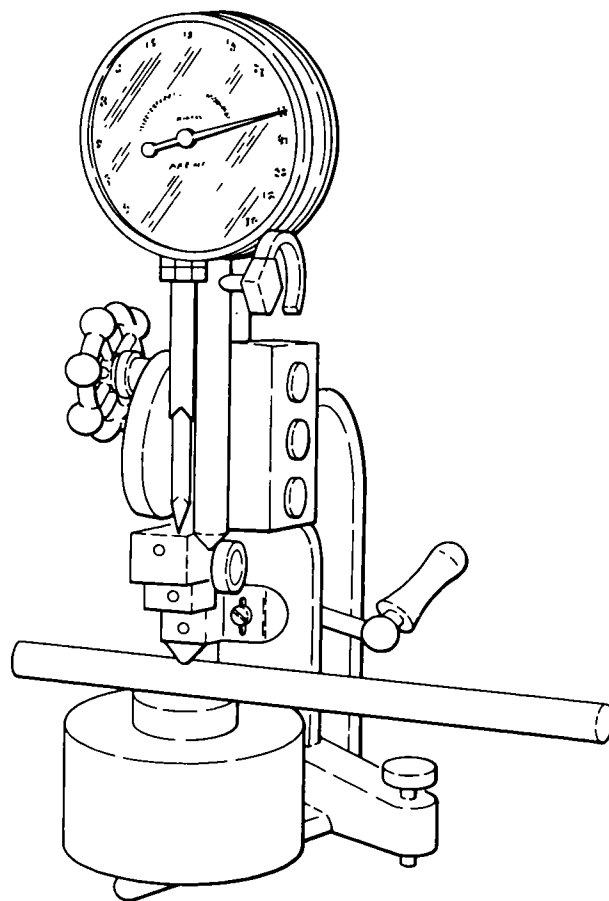


Figure 27. Scleroscope tester.

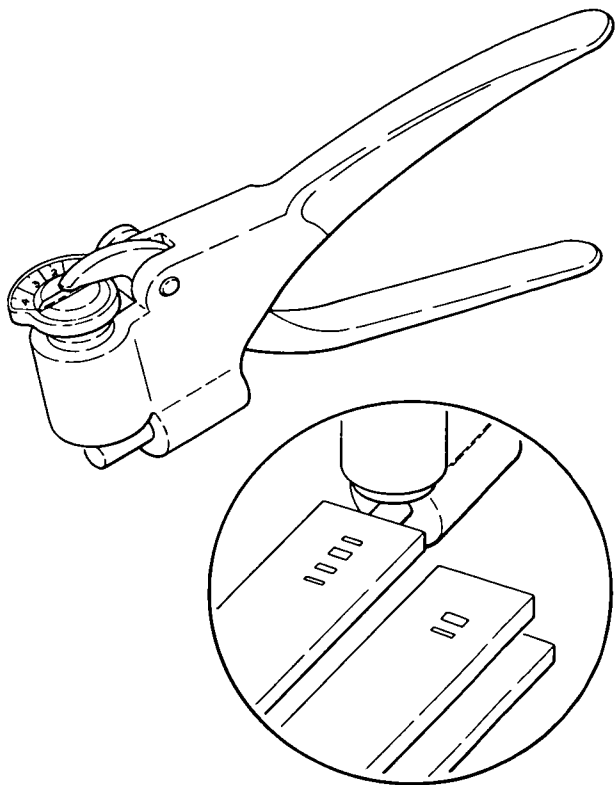


Figure 28. Webster hand-type tester.

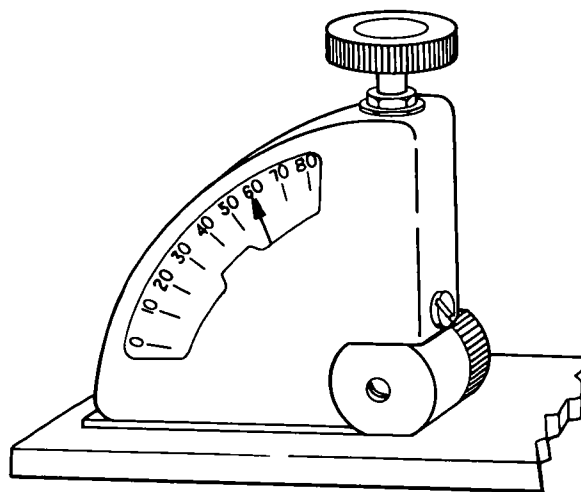


Figure 29. Shore durometer.

CHAPTER 4

SHEET METAL TOOLS AND SHOP EQUIPMENT

Section I. GENERAL

29. Tools and Shop Equipment

This chapter contains general instructions on the sheet metal tools and shop equipment used by the airframe repairman in performing aircraft structural repairs. In the absence of large power presses and dies or heavy drop hammers on the flight line or in the depot to shape out the parts needed, and in the absence of the services of engineers and draftsmen to furnish data or layout measures required to make repairs, the airframe repairman must be familiar with the use of these tools and equipment. The airframe repairman should be able to select the material, estimate original and final temper conditions, take measurements, make the layout, and in some cases design and make the necessary forms or dollies on which to shape a repair part. A thorough understanding of these instructions, methods, and procedures will be a great asset to the airframe repairman.

30. Tool Care and Selection of Tools

Tool care and the selection of tools are very important to the airframe repairman. Improper selection, use, and care of tools can be causes of injury to personnel, material waste, and equipment damage.

a. The efficiency of the airframe repairman and the tools used are determined to a great extent by the condition in which the tools are kept. Tools should be wiped clean and dry before being placed in a tool box. If the use of tools is not anticipated in the near future, each tool should be lubricated to prevent rust. This is especially true if tools are to be stored under conditions of extremely humid or salt air.

b. The selection of the proper tool to fit the job is of prime importance. Proper choice of tools enables the airframe repairman to perform his work on time, accurately, and safely.

Section II. BASIC HAND TOOLS

31. Layout and Measuring Tools

Layout and measuring tools are precision design tools, carefully machined and accurately marked. Some are made up of very delicate parts. Care should be exercised when using them to avoid bending, dropping, and/or other misuse which would impair their performance. The outcome of the job depends upon the accuracy of measurements and layout made by the airframe repairman; therefore, it is important to fully understand the reading, usage, and care of these tools.

a. *Rules.* Rules are generally made of steel, in lengths of 4, 6, and 12 inches. The inch is the most commonly used unit of measurement in aircraft metalwork. The rule has graduated markings expressed in divisions of $1/2$, $1/4$, $1/8$, $1/16$, $1/32$, and $1/64$ inch. The fractions of an inch may be expressed in decimals, called decimal equivalents of an inch; for example, $1/8$ inch is expressed as 0.125 (one hundred and twenty-five thousandths of an inch). Rules are manufactured in two basic styles: those divided or marked

in common fractions, as shown in figure 30, and those divided or marked in decimals or divisions of one-hundredths of an inch. A rule may be used either as a measuring tool or as a straight-edge. To obtain an accurate dimension, the rule should be turned on edge and sighted down the graduations. Since the end of a rule may become worn or damaged, greater accuracy can be obtained by measuring from one of the internal graduations (fig. 30). Read the graduated markings on rule that is at point on rule where the other end of the line stops.

b. *Tapes.* There are several kinds and lengths of tapes, but the most commonly used is 6 feet long and made of flexible steel, coiled in a circular case as shown in figure 30. It is graduated on one side in divisions of $1/2$, $1/4$, $1/16$, and $1/32$ inch. A small lip on the extending end is used to steady the tape while measuring. The tape will bend, but it should not be bent intentionally, as it may be broken easily.

c. Irregular Curves. Curved rulers, called irregular curves or sometimes french curves, as shown in figure 31, are used as mechanical guides for drawing curved lines other than circle arcs. The curves are made in patterns which feature parts of ellipses and spirals or other mathematical curves in various combinations. These curves are usually manufactured from transparent plastic. To use this tool, a sufficient layout of plotted fixed points are needed. When these points have been determined and marked, align the edge of the curve to these points by selecting portions of the curve which fit these points. Using a suitable marking pencil, produce a curved line by following the curved edges contacting the plotted fixed points. The complete layout will be determined by successive positioning of the curve until the line drawn covers all the points. In shifting the curve, care should be taken to preserve smoothness and continuity of the drawn line. This can be accomplished by positioning the curve so that it coincides for a short distance with part of the line already drawn. The curve should always be kept flat to avoid warpage.

d. T-Squares. T-squares are made with a fixed head or an adjustable head. The T-square most often used has a hardwood blade with transparent plastic edges and attached rigidly to a hardwood head as shown in figure 31. The head of the T-square is placed at the left edge of the workboard (for a right-handed worker) and is held firmly while drawing. This arrangement places the upper edge of the blade and the inner edge of the head at right angles; these are the working edges of the T-square. The blade is used to draw horizontal lines. Vertical or sloping lines are made with the aid of triangles. The T-square should always be held flat on the work area. Care should be exercised to avoid marring the blade edges.

e. Triangles. Triangles are usually made of transparent celluloid or plastic material. Two triangles are usually desirable, a 30-60-degree triangle and a 45-degree triangle as shown in figure 31. Standard sizes are 10 inches for legs of 45-degree triangle. Vertical and sloping lines are drawn with use of triangles. The base of the triangle should rest flat and on edge of the blade of the T-square. Care should be exercised to avoid marring the edges.

f. Combination Set. The combination set, as shown in figure 32, is a tool that has several uses. The set is comprised of—a 12-inch grooved steel blade with graduated markings similar to a 12-inch rule, a cast steel center head, a cast steel protractor head, and a cast steel stock

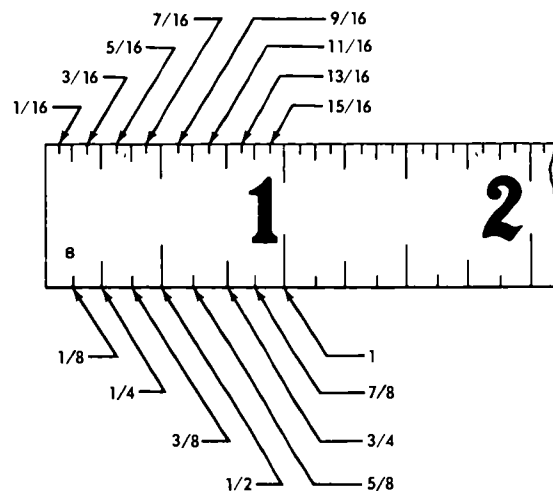
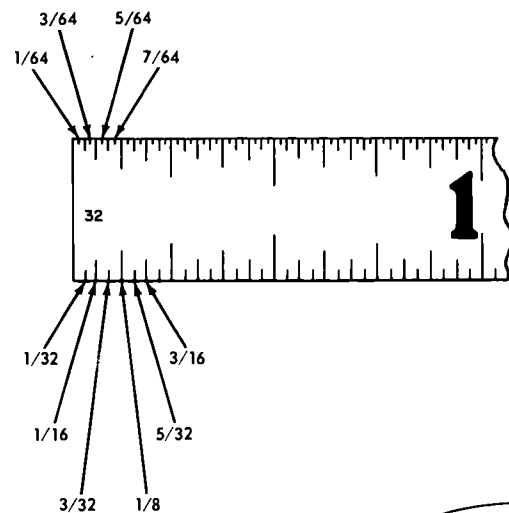
head. Each of the heads is made to slide along the blade and clamp at any desired position. The center head is used to find the center of shafting or other cylindrical work. The protractor head can be set at any desired angle and used to draw lines other than 45-degree lines. The stock head, sometimes called square head, has a spirit level and a scribe. It can be used to square material surface points, plumb and level, at the same time. It can also be used as a simple level.

g. Scribe. The scribe, as shown in figure 33, is made of tool steel, 4 to 12 inches long, and has two needle-pointed ends. One end is bent at a 90° angle for reaching and marking through openings. The scribe is designed to serve the airframe repairman in the same way a pencil or pen serves a writer. In general, it is used to scribe or mark lines on metal surfaces. Before using a scribe always inspect the points for sharpness. Be sure the steel rule being used as a straightedge is flat on the metal and in position for scribing. Tilt the scribe slightly in the direction toward which it will be moved, holding it like a pencil. Keep the scribe's point close to the guiding edge of the steel rule. The scribed line should be heavy enough to be visible, but no deeper than necessary to serve its purpose.

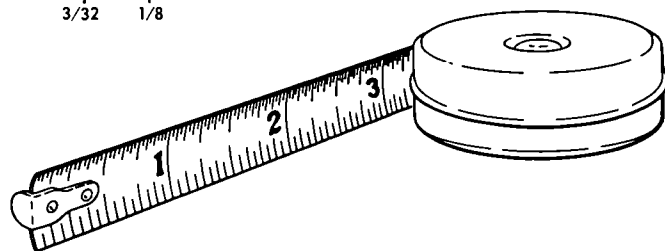
h. Dividers. Dividers are used for measuring distances between two points, for transferring or comparing measurements directly from a rule, or for scribing an arc, radius, or circle. Figure 34 illustrates two types of dividers: the spring type and wing type. The spring divider consists of two sharp points at the end of straight legs, held apart by a spring and adjusted by means of a screw and nut. The spring divider is available in sizes from 3 to 10 inches in length. The wing divider has a steel bar that separates the legs, a locking nut for securing a rough measurement, and an adjusting screw for fine adjustments. The wing divider is available in 6-, 8-, and 12-inch lengths. An improved version of the wing divider has the tip of one leg removable so that a pencil can be inserted.

(1) To set the dividers, hold them so that one leg will be positioned at a determined mark on material or rule, turn adjustment nut, and bring the other leg to rest on material or rule at point of required measurement.

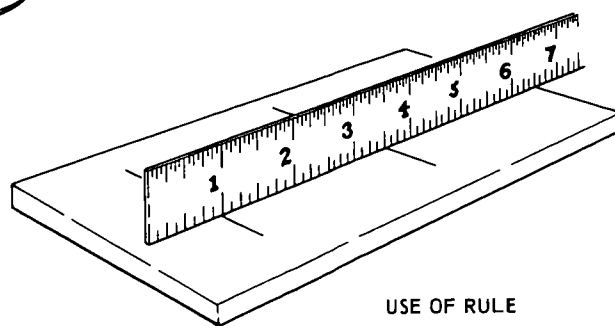
(2) To draw an arc or circle with a divider, hold the top with thumb and forefinger, position one leg on determined center point. Exert snug down pressure on this leg and apply swing pressure to other leg in a drag fashion,



RULES



FLEXIBLE STEEL TAPE



USE OF RULE

Figure 30. Rules and tape.

allowing point to mark line for arc or circle. The tendency for the legs to slip can be avoided by inclining the dividers in the direction they are being rotated.

i. Calipers. Calipers are used for measuring diameters or comparing distances and sizes. The four common types of calipers are: inside calipers, outside calipers, slide calipers, and hermaphrodite calipers (fig. 35). These calipers have setting and adjustment features which can be manipulated to measure work as required. There are also a number of special types of calipers, such as gear tool calipers.

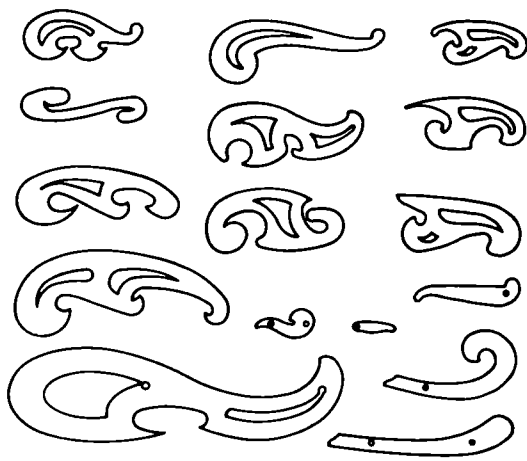
(1) *inside calipers.* Inside calipers have legs that are curved outward for measuring inside diameters, such as diameters of cylinder bores and holes; the distance between two surfaces; the width of slots; and other similar measurements. The setting and adjustment knob and screw should be locked securely when measurement points have been made, as this assures accuracy when making reading of caliper measurement.

(2) *Outside calipers.* Outside calipers have legs that are curved inward for measuring outside dimensions of round stock, such as shafts,

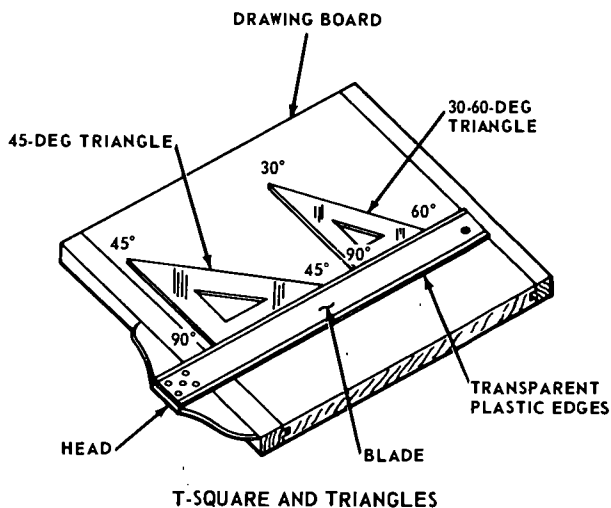
pipe, rods, and other objects. Setting and adjustment methods are similar to methods used with inside calipers.

(3) *Slide calipers.* The slide caliper, sometimes called the slide caliper rule, eliminates the use of a regular scale rule. The slide caliper, as shown in figure 35, has a vernier scale for use in extremely close readings. The blade of the caliper is graduated in fortieths, or 0.025 of an inch, every fourth division, representing a tenth of an inch being numbered. On the vernier scale is a space divided into 25 parts and numbered 0, 5, 10, 15, 20, 25. The 25 divisions on the vernier scale occupy the same space as 24 divisions on the caliper blade. To read the slide caliper, note how many tenths (or 0.100 and fortieths, or 0.025) the zero mark on the vernier scale is from the zero mark on the caliper blade; then note the number of divisions on the vernier scale from zero to a line which exactly coincides with a line on the blade.

(4) *Hermaphrodite calipers.* Hermaphrodite calipers have a point on one leg and a bearing surface on the other. They are used to scribe lines or arcs on material in layout work, and should never be used for precision measurement.



IRREGULAR (FRENCH) CURVES



T-SQUARE AND TRIANGLES

Figure 31. Irregular curves, T-squares, and triangles.

j. *Micrometer Calipers.* Micrometer calipers are the most accurate of all the adjustable measuring instruments. There are four types of micrometer calipers and each are designed for specific use. These calipers are called by name according to their use: outside micrometer, inside micrometer, depth micrometer, and thread micrometer. The internal parts of the micrometers are cut on a precision machine grinder. The outside micrometer, as shown in figure 36, is most commonly used by the airframe repairman.

(1) *Outside micrometer.* The outside micrometer is used to measure outside dimensions of shafts and round stock, and to make other similar measurements. It is also used to set inside calipers to a given dimension.

(2) *Inside micrometer.* The inside micrometer is used to measure the inside diameters of cylinders, the width of recesses, and other similar measurements.

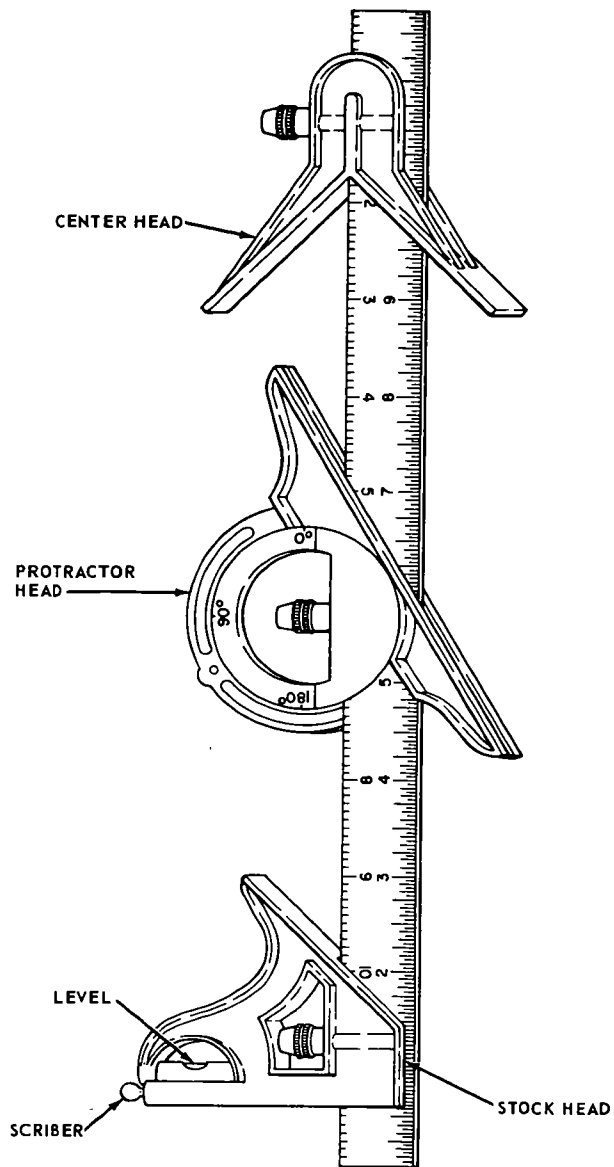


Figure 32. Combination set.

(3) *Thread micrometer.* The thread micrometer is used to measure the pitch diameters of screws and bolts.

(4) *Depth micrometer.* The depth micrometer is used to measure the depth of recesses or holes.

(5) *Parts of a micrometer.* The fixed parts of a micrometer are the frame, barrel, and anvil; the movable parts are thimble and spindle. The thimble rotates the spindle which moves in the threaded portion inside the barrel. Turning the thimble provides an opening between the anvil and the end of the spindle where the work is measured.

The decimal system is a method of expressing fractions and mixed numbers. For example, $2 \frac{1}{2}$ inches written decimally, would be expressed



Figure 33. Scriber.

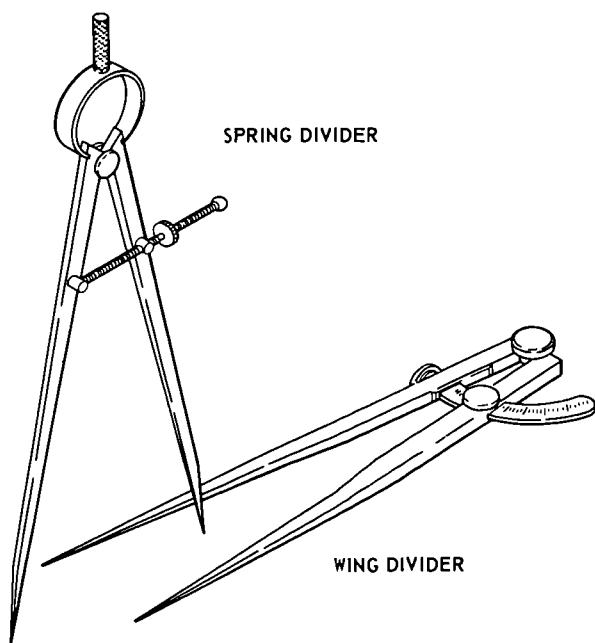


Figure 34. Dividers.

as 2.5 inches. All figures to the left of the decimal point are whole numbers; all figures to the right indicate parts of whole numbers. Starting from the decimal point and moving to the right, the first digit indicates tenths; the second, hundredths; the third, thousandths; the fourth, ten-thousandths; and so on. Thus, 2.3 is read two and three tenths; 2.35 is read two and thirty-five hundredths; 0.2351 is read twenty-three hundred and fifty-one ten-thousandths. (When there is no number to the left of the decimal point, the quantity is less than one.)

(6) *Reading a micrometer.* All micrometers are read in a similar manner. The method discussed in the following steps pertains to the reading of an outside micrometer. The smallest measurement which can be made with the use of the steel rule is one sixty-fourth of an inch in common fractions, and one one-hundredth of an inch in decimal fractions. To measure in smaller dimensions which cannot be accomplished with a rule or tape (in thousandths and ten-thousandths of an inch), a micrometer is used. If a dimension given in a common fraction is to be measured with the micrometer, the fraction must be converted to its decimal equivalent.

(a) The barrel of the micrometer is marked in equal spaces which determine the number of revolutions made by the thimble. The lines on the barrel marked 1, 2, 3, 4, etc., indicate measurements of tenths, or 0.100, 0.200, 0.300, 0.400 inch respectively, as shown in figure 37.

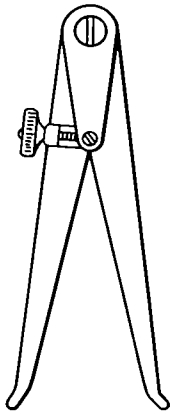
(b) The outside of the thimble has a beveled edge which is divided in 25 equal spaces. Each of these spaces represents one twenty-fifth of the distance the thimble travels along the barrel in moving from one of the 0.025-inch divisions to another. Thus, each division on the thimble represents one one-thousandths (0.001) of an inch. These divisions are marked for convenience at every five spaces by 0, 5, 10, 15, and 20, as shown in figure 38. When 25 of these graduations have passed the horizontal line on the barrel, the spindle (having made one revolution) has moved 0.025 inch.

(c) The micrometer is read by first noting the last visible figure on the horizontal line of the barrel representing tenths of an inch. Add to this reading the visible graduations shown on the barrel between the thimble and the previously noted number. (This is found by multiplying the number of graduations by 0.025 inch.) Add to this the number of divisions on the bevel edge of the thimble that coincides with the line of graduations on the barrel. Add all these figures together; the total is the measurement. Sample micrometer readings are shown in figure 38.

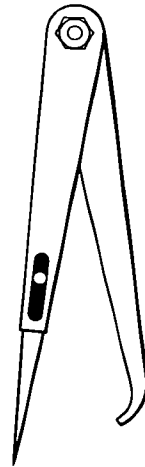
(7) *Vernier scale.* Some micrometers are equipped with a vernier scale which makes it possible to read directly the fraction of a division that may be indicated on the thimble scale. The vernier scale is a series of 11 lines marked off in 10 spaces parallel to the centerline of the micrometer barrel. The space between any two of these lines is equal to nine-tenths of the space between two marks on the thimble. Typical examples of the vernier scale as it applies to the micrometer are shown in figure 39. The following instructions apply to vernier scale reading.

(a) All three scales on a micrometer are not fully visible without turning the micrometer; but the examples shown in figure 39 are drawn as though the barrel and thimble of the micrometer were laid out flat so that all three scales can be seen at the same time. The barrel scale is the lower horizontal scale; the thimble scale is vertical on the right; and the long horizontal lines (0 through 9 and 0) make up the vernier scale.

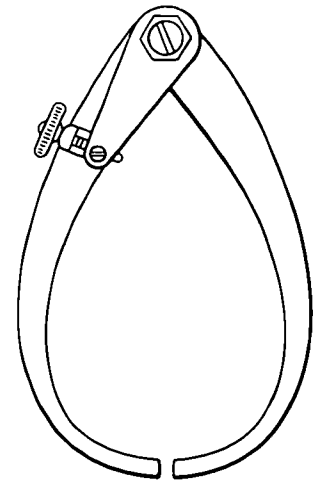
(b) In reading a micrometer, an excellent way to remember the relative scale values



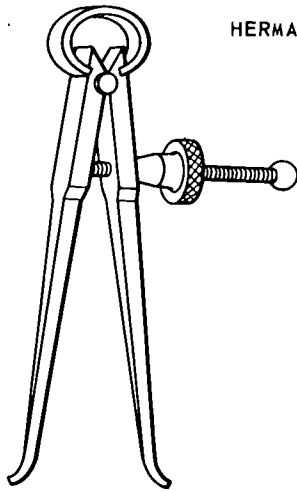
FIRM JOINT SCREW
ADJUSTING INSIDE
CALIPERS



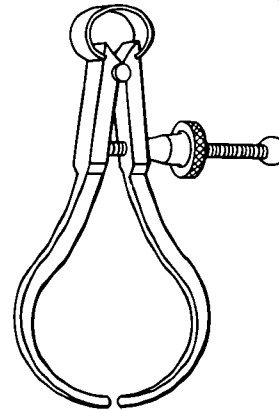
HERMAPHRODITE CALIPERS



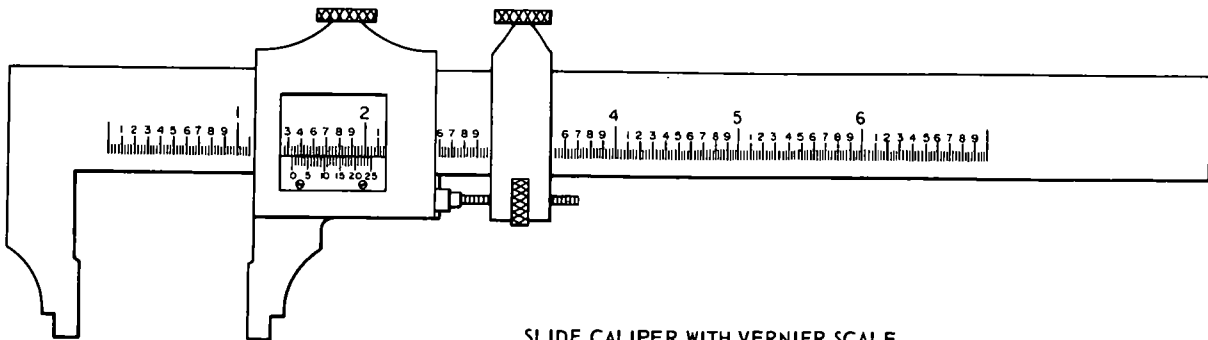
FIRM JOINT SCREW
ADJUSTING OUTSIDE
CALIPERS



SPRING INSIDE CALIPERS



SPRING OUTSIDE CALIPERS



SLIDE CALIPER WITH VERNIER SCALE

Figure 35. Calipers.

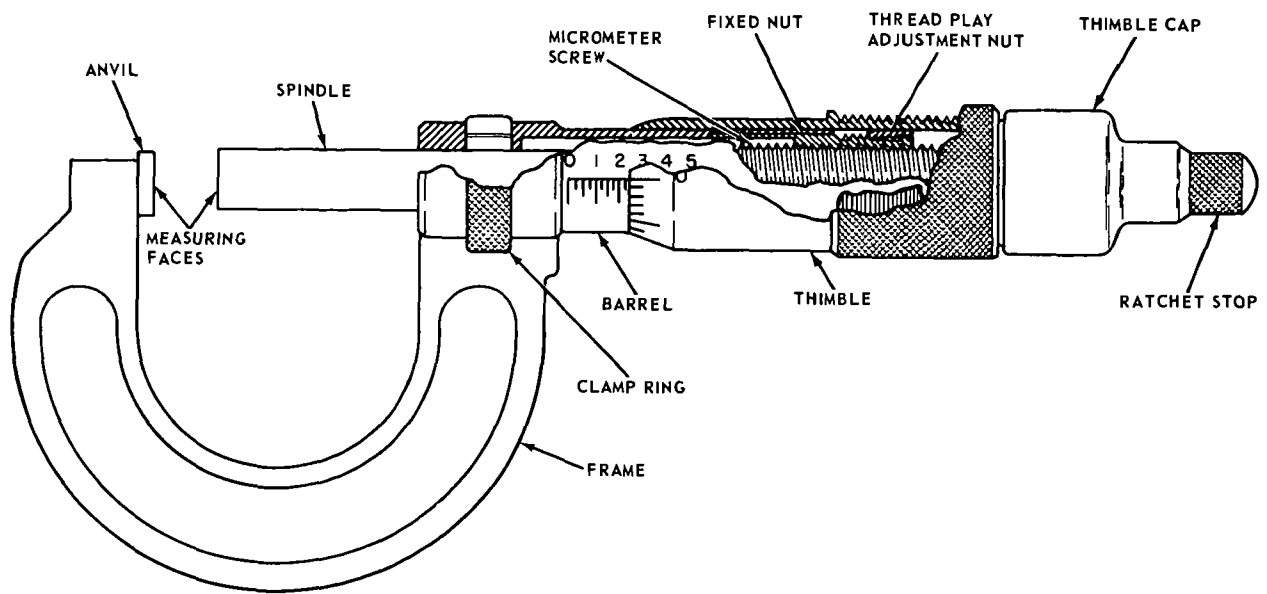


Figure 36. Outside micrometer.

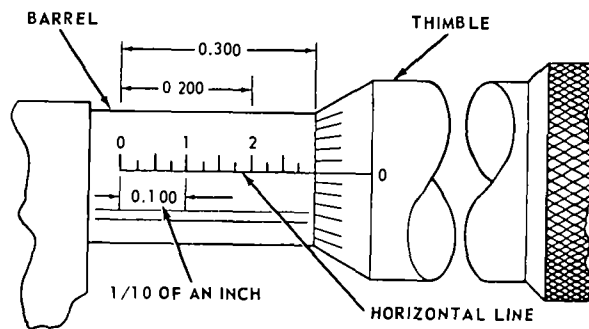


Figure 37. Micrometer measurements.

is to remember that the 0.025-inch barrel scale graduations are established by the lead screw. Next, the thimble graduations divide the 0.025 inch into 25 parts, each equal to 0.001 inch; then the vernier graduations divide the 0.001 inch into 10 equal parts, each equal to 0.0001 inch. Remembering the values of the various scale graduations, the barrel scale reading is noted; then the thimble scale reading is added to it; then the vernier scale reading is added to get the final reading. The vernier scale line to be read is always the one aligned exactly with any thimble graduation.

(c) In the first example in figure 39, the barrel reads 0.275 inch and the thimble reads 0.019 inch. This graduation is aligned exactly with the barrel reference line, and the vernier zeros are both aligned so that there is no decimal part of a division to be added. Notice that none of the vernier lines between the two zeros coin-

cide with a line on the thimble. So, the final reading is 0.294 inch.

(d) In the second example in figure 39, the barrel reads 0.275 inch and the thimble reads more than 0.019 inch and less than 0.020 inch. On the vernier scale, the number 4 graduation coincides with a line on the thimble. This means that the thimble reading would be 0.0194 inch. Adding this to the barrel reading of 0.275 inch would give a total measurement of 0.2944 inch.

(8) *Using a micrometer.* The micrometer must be handled carefully. If it is dropped, its accuracy may be permanently affected. The anvil and spindle surfaces may become worn through process of continually sliding work in and out of the micrometer. If the spindle is tightened too much, the frame may be sprung permanently and inaccurate readings will result. Measure work with the micrometer as follows:

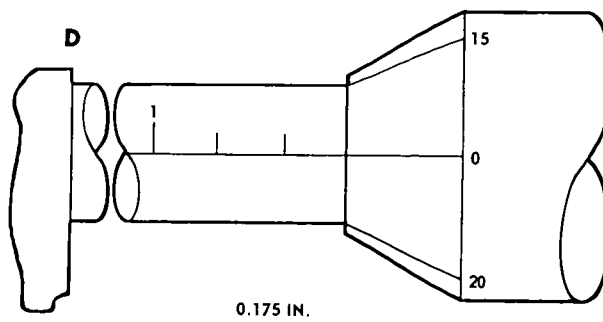
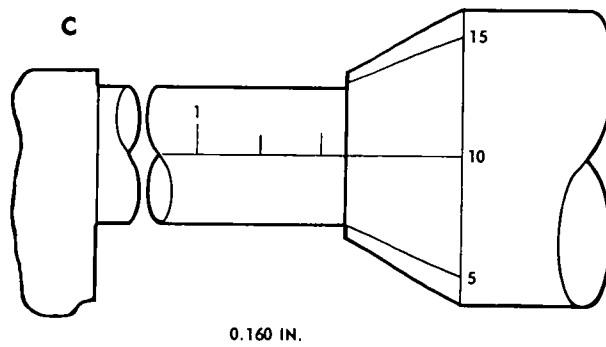
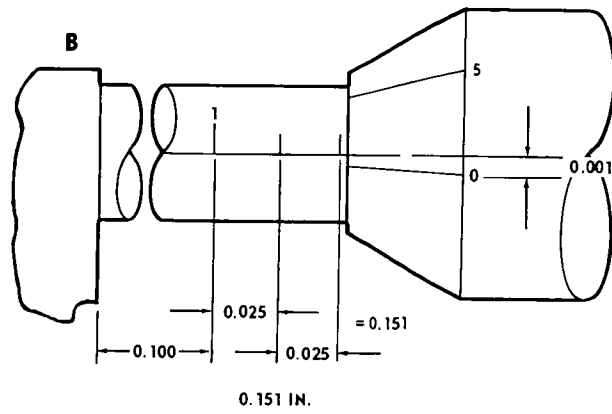
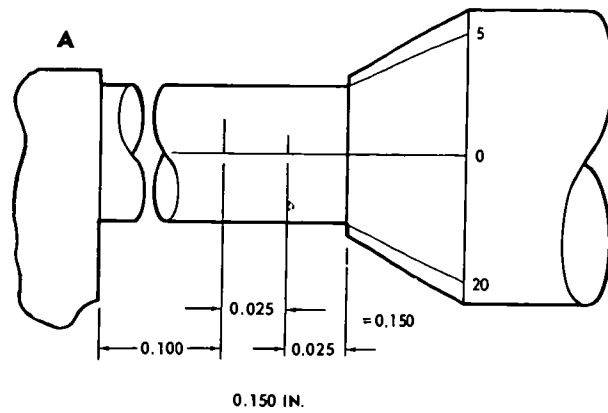
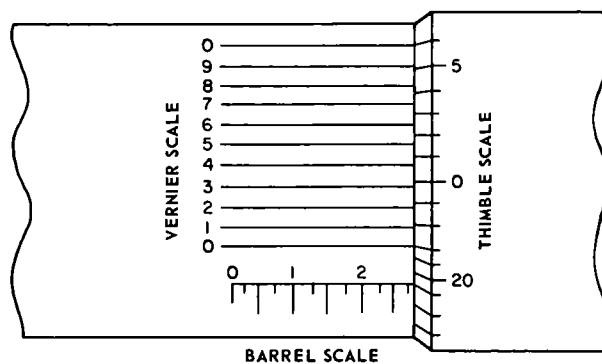
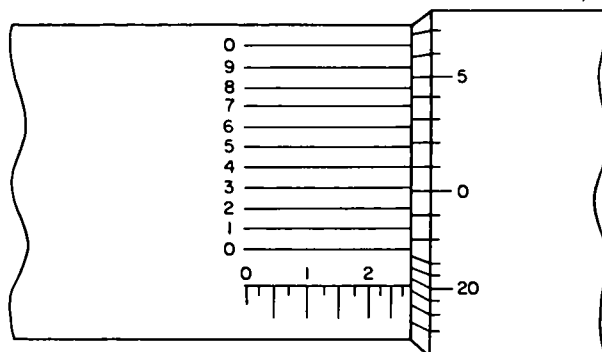


Figure 38. Micrometer readings.



A 0.2940



B 0.2944

Figure 39. Vernier scale readings.

(a) The proper way to hold a micrometer in checking a small part is shown in A, figure 40. Hold the part in one hand. Hold the micrometer in the other hand so that the thimble rests between the thumb and the forefinger. The third finger is then in a position to hold the frame against the palm of the hand. The frame is supported in this manner and makes it easy to guide the work over the anvil. The thumb and forefinger are in position to turn the thimble either directly or through the ratchet and bring the spindle over against the work.

(b) On larger work, it is necessary to have the work stationary and positioned to permit access to the micrometer. The proper method of holding a micrometer when checking a part too large to be held in one hand is shown in B, figure 40. The frame is held by one hand to position and to locate the frame square to the measured surface. The other hand operates the thimble either directly or through the ratchet. A large flat part should be checked in several places to determine the amount of variation.

(c) To gage a shaft as shown in C, figure 40, the frame is held by one hand while the thimble is operated by the other. In gaging

a cylindrical part with a micrometer it is necessary to feel the setting to be sure that the spindle is on the diameter, and also to check the diameter in several places to determine the amount of out-of-roundness.

k. *Gages*. Gages are measuring instruments that are fixed. They have a series of openings of definite width, or leaves of definite thickness. They are made of hard steel so as not to lose their accuracy with use. Gages most generally used by the airframe repairman are listed in the following steps.

(1) *Thickness gage*. The thickness gage has a series of thin leaves, each ground to a definite thickness which is marked on the leaf. The leaves are usually in sets, with one end fastened in a case. Figure 41 shows a typical thickness gage. The thickness gage is used to measure clearances. The leaf should be clean before attempting to insert it into the opening. Two leaves may be used together when a leaf of the proper thickness is not available.

(2) *Twist-drill gage*. The twist-drill gage is a smooth-finish steel plate, round or rectangular, containing a series of round holes that correspond in size to a series of drills. The twist-

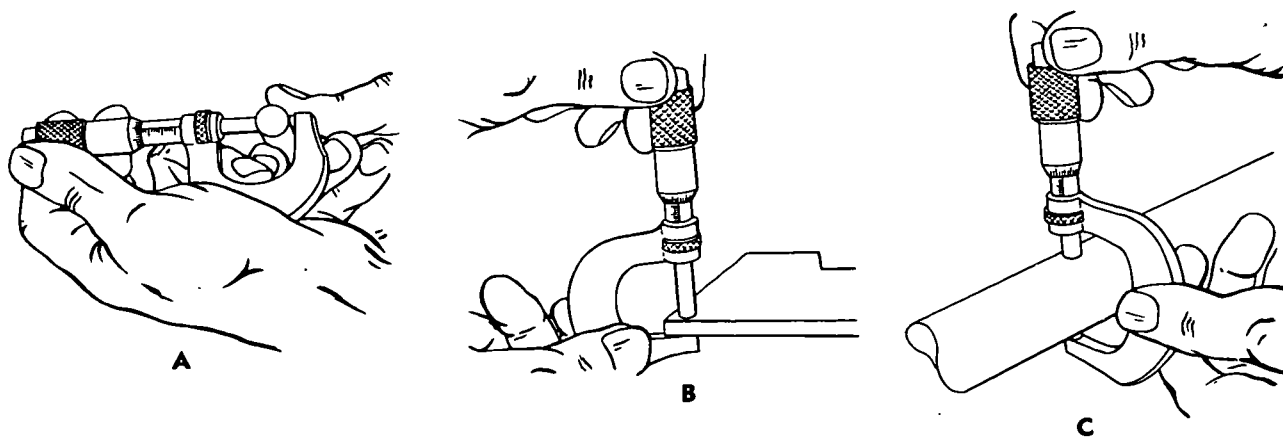


Figure 40. Using a micrometer.

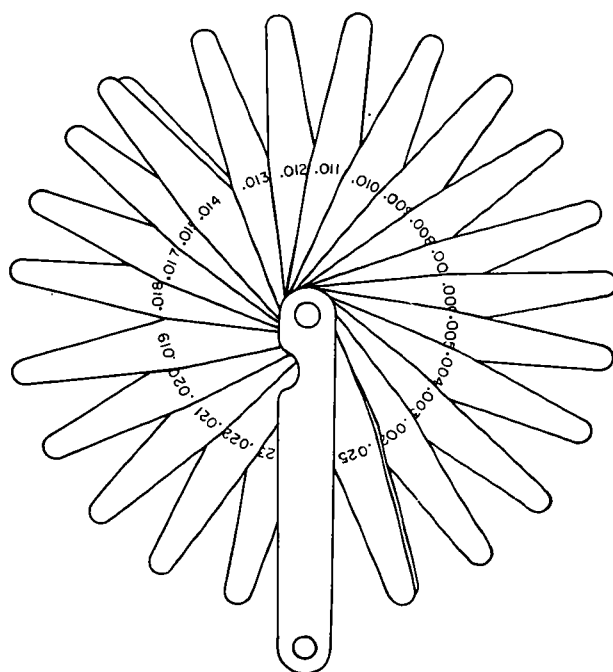


Figure 41. Thickness gage.

drill gage is used when it is necessary to drill a hole for wire, a rivet, or similar stock. The proper size drill may be selected by fitting the stock in the holes of the twist-drill gage. The gage is also used to determine sizes of drills corresponding to size markings as shown in figure 42.

(3) *Sheet metal and wire gage.* The sheet metal and wire gage is very similar to the twist-drill gage, except for gage slots on the outer edge. There are several standard gages, such as American Standard, English Standard, and U.S. Standard. The American Standard, as shown in figure 43, is the most commonly used gage for aircraft sheet metal and wire. The thickness of sheet metal or wire may be determined by

placing the sheet metal or wire into the slots of the gage until the correct fit is found.

(4) *Thread gage.* The thread gage is similar to the thickness gage, except the leaves are all of the same thickness and the edges of the leaves have teeth. The number of teeth per inch is marked on each leaf, and the number varies from leaf to leaf. The thread gage is used to determine the threads per inch on bolts and screws by selecting the leaf of the gage that corresponds to the threads of a bolt or screw, as shown in figure 44.

(5) *Radius gage.* The radius gage is similar to the thickness gage, except all leaves have the same thickness and the sides of each leaf are curved at a definite radius. The radius is

marked on each leaf. The radius gage, as shown in figure 45, is used to determine the radius of curved surfaces by selecting the leaf of the gage that corresponds to the surface being gaged.

(6) *Drill grinding gage and use.* The drill grinding gage, as shown in figure 46, is shaped like the letter T, with the ends of the crossbar of the T cut off at an angle of 59 degrees. This is

 1/4 INCH DRILL & WIRE GAUGE INDEX FOR MACHINE SCREW TAPS			
TAP SIZE	TAP	DRILL	BODY DRILL
2 - 56	50	44	
2 - 64	50	44	
3 - 48	47	39	
3 - 56	45	39	
4 - 36	44	33	
4 - 40	43	33	
4 - 48	42	33	
5 - 40	38	1/8	
5 - 44	37	1/8	
6 - 32	36	28	
6 - 40	33	28	
8 - 32	29	19	
8 - 36	29	19	
10 - 24	25	11	
10 - 32	21	11	
12 - 24	16	7/32	
12 - 28	14	7/32	
14 - 20	10	C	
14 - 24	7	C	
1/4 - 20	7	1/4	
1/4 - 28	3	1/4	
DECIMAL EQUIVALENTS			
 .228	 .140	 .136	 .040
 .144	 .128	 .041	 .058
 .221	 .147	 .120	 .042
 .213	 .149	 .116	 .043
 .209	 .152	 .113	 .046
 .205	 .154	 .111	 .052
 .204	 .159	 .106	 .053
 .201	 .161	 .104	 .059
 .199	 .166	 .101	 .063
 .196	 .169	 .099	 .067
 .193	 .173	 .098	 .070
 .191	 .177	 .096	 .073
 .189	 .180	 .093	 .076
	 .182	 .089	 .078
	 .185	 .086	 .081
		 .082	 .082

Figure 42. Twist-drill gage.

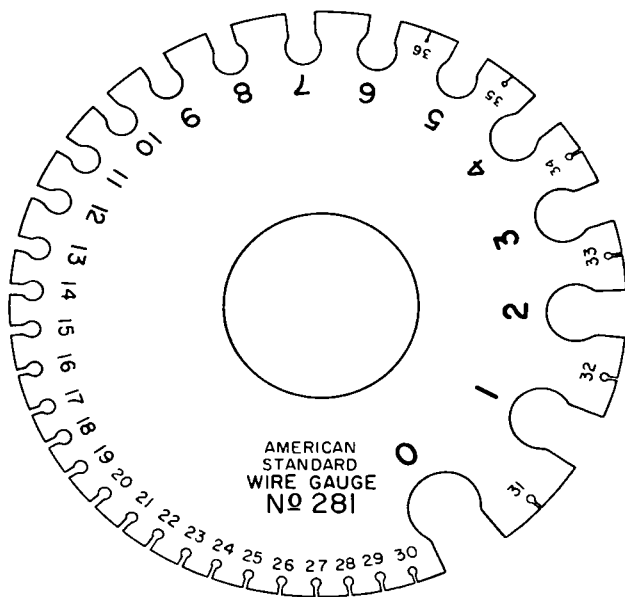


Figure 43. Sheet metal and wire gage.

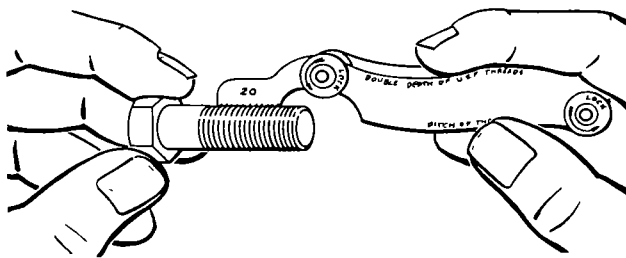


Figure 44. Using thread gage.

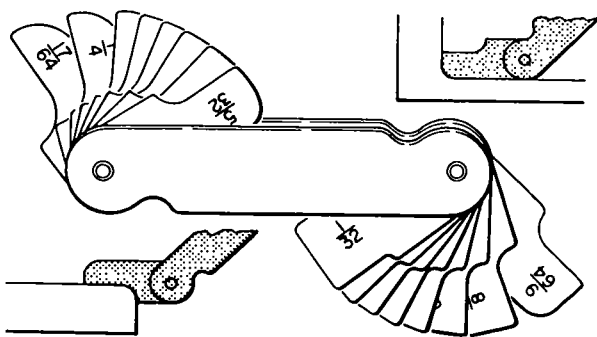


Figure 45. Radius gage.

the correct angle for cutting lips of a drill. The edge of the gage is marked in 1/8-inch divisions to measure the length of the lips as well as the angle of the drill.

32. Holding Tools

There are several types of holding devices used when working sheet metal, including sheet metal screws. The type of operation being performed and the type of metal being used determine the holding tools to use. The following instructions

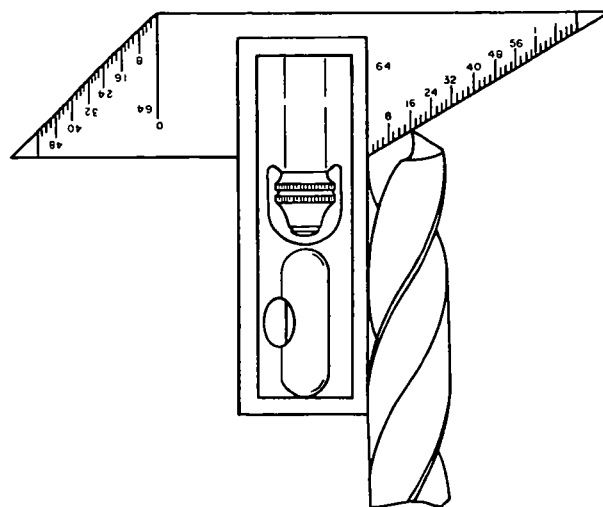


Figure 46. Drill grinding gage.

cover the most common holding tools used by the airframe repairman.

a. *Sheet Metal Holders.* General shop vises, such as the utility bench vise, machinist vise, and blacksmith vise, are used in almost all airframe metal-working. The utility bench vise is designed to hold heavier material, and the back can be used as an anvil to do light work. The machinist vise has a swivel base and flat jaws. The blacksmith vise is similar to the machinist vise except that it has a leg that extends to floor level which enables the vise to hold material for pounding hard with a hammer. The following holding devices are also used in airframe metalworking.

(1) *Cleco fasteners.* The cleco fastener is a popular device for holding metal. It is used to keep drilled parts made from sheet metal stock pressed tightly together to prevent slipping or separation while riveting or fastening. This type fastener is available in six different sizes—3/32, 1/8, 5/32, 3/16, 1/4, and 3/8 inch. The size is stamped on the fastener. The holding feature of the cleco fastener is shown in figure 47. Special pliers are used to insert the cleco fastener.

(2) *C-clamp.* The C-clamp shown in figure 48 is shaped like a large C and has three main parts—the threaded screw, the jaw, and the swivel head. The swivel head, which is at the bottom of the screw, prevents the end from turning directly against the material being clamped. Although these clamps vary in size from 2 inches upward, their function is always that of holding or clamping. The shape of the C-clamp allows it to span obstructions near the edge of a piece of work. The greatest limitation in the use of the C-clamp is its tendency to spring out of shape. It should never be tightened more than handtight.

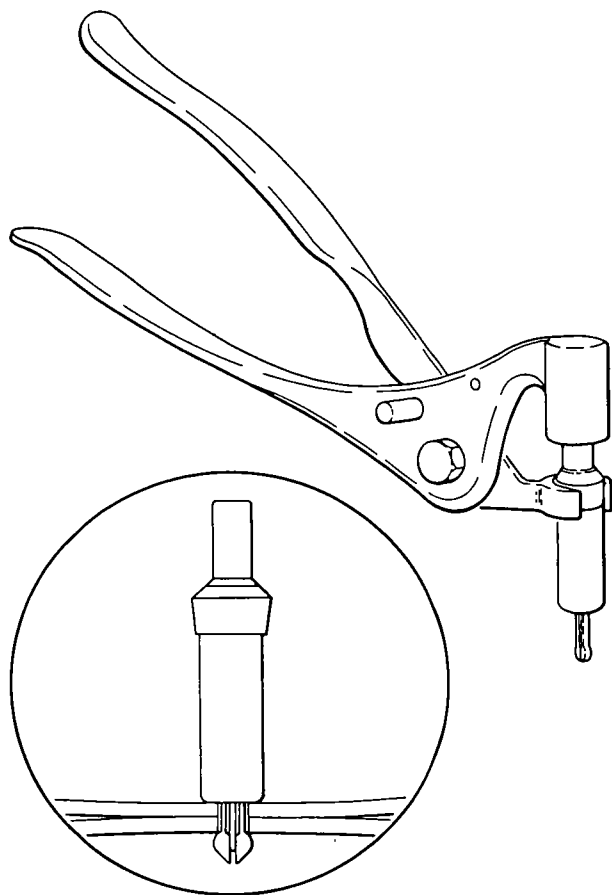


Figure 47. Cleco fastener.

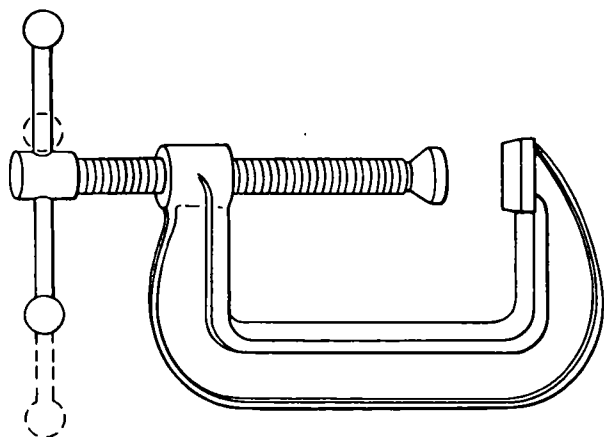


Figure 48. C-clamp.

b. *Pliers*. Several types of pliers are used in airframe work (fig. 49). The most frequently used pliers are the combination, flatnose, roundnose, flatnose, side-cutting, half-roundnose, diagonal cutting, crimping, clamp pliers, and special pliers for inserting cleco fasteners. The sizes of the pliers indicate their overall length, usually ranging from 5 to 12 inches.

(1) *Combination pliers*. These pliers are all-purpose tools. The 6-inch combination slip-joint

pliers, usually called combination pliers, are the more preferred size for use in repair work. The slip-joint permits the jaws to be opened wider at the hinge for gripping large diameters. The pliers come in sizes from 5 to 10 inches. The better grades of combination pliers are drop-forged steel and are used principally for holding and bending flat or round stock.

(2) *Flatnose pliers*. Flatnose pliers are very satisfactory for making flanges. The jaws are square, fairly deep, and usually well matched, and the hinge is firm. These characteristics serve to give a sharp, neat bend.

(3) *Roundnose pliers*. These pliers are used to crimp metal. They are not designed for heavy work, as too much pressure will spring the jaws which are often wrapped to prevent scarring the metal.

(4) *Half-roundnose pliers*. These pliers have half-round jaws of varying lengths. They are used to hold objects and make adjustments in tight places.

(5) *Diagonal cutting pliers*. These pliers, usually referred to as diagonals or dikes, are short-jawed cutters with a blade set at a slight angle on each jaw. This tool can be used to cut wire, rivets, small screws, small bolts, and cotter pins. Also, it is a good tool to use for removing or applying safety wire.

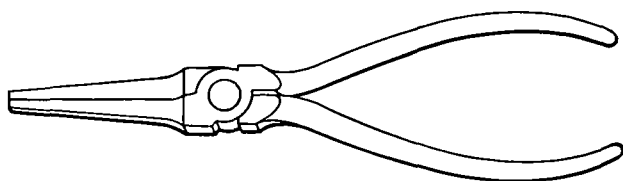
(6) *Crimping pliers*. These pliers have practically the same design as the ordinary roundnose pliers. Since a crimp is made by twisting rather than clamping, crimping pliers are constructed of heavier material to withstand the heavy side load caused by the twisting action. It is a sound procedure to keep the points of the pliers covered with adhesive tape or similar material to avoid scratching or marring the metal.

(7) *Cleco fastener pliers*. These pliers are used to insert the cleco fastener as shown in figure 47. One pair will fit all six sizes of cleco fasteners.

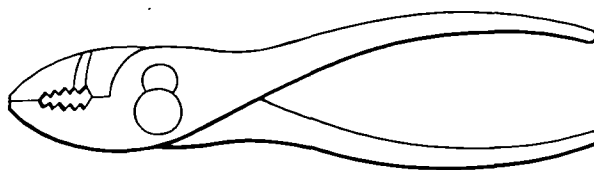
(8) *Flatnose side-cutting pliers*. Flatnose side-cutting pliers are used to bend or form metal into various shapes and to work in limited spaces. These pliers are equipped with side-cutters for cutting wire and metal and are available in different sizes.

(9) *Clamp pliers*. Clamp pliers are used for bending sheet metal and locking templates to blank sheets. They are also used for holding metal for welding. The pliers lock the work with a powerful grip and keep it from slipping. The grip can be adjusted for different thicknesses of metal by turning the screw located in the end of the handle.

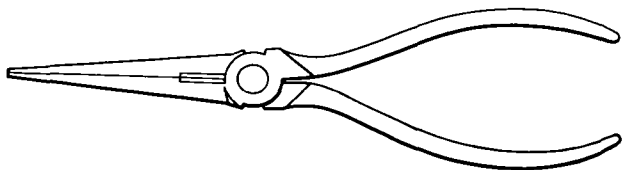
c. *Wrenches*. The wrenches most often used by the airframe repairman are classified as open-



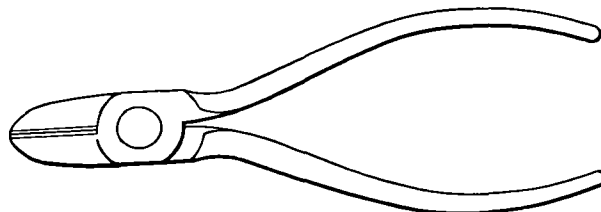
FLATNOSE PLIERS



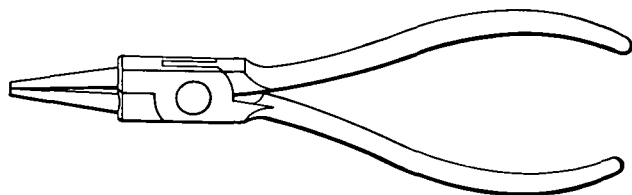
COMBINATION PLIERS



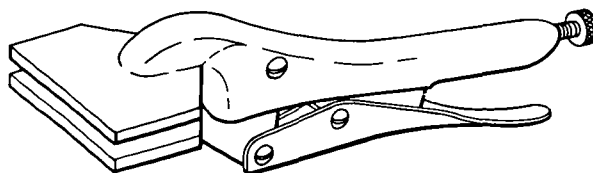
FLATNOSE SIDE-CUTTING PLIERS



DIAGONAL CUTTING PLIERS



ROUNDNOSE PLIERS



CLAMP PLIERS

Figure 49. Pliers.

end, box-end, combination, socket, adjustable, and special wrenches. Most of the wrenches are made of chrome-vanadium steel (fig. 50).

(1) *Open-end wrenches.* These wrenches have solid, nonadjustable, open, parallel jaws on one or both ends, as shown in figure 50. They are usually in sets of 6 to 12 wrenches having a series of jaw sizes ranging from 5/16 to 1 inch. Some have jaws parallel to the handle or at an angle up to 90°; most set at an angle of 15°. Basically, the wrench is designed to fit a nut, bolthead, stud, or other object, which makes it possible to exert a turning action force for loosening, tightening, or removing an item.

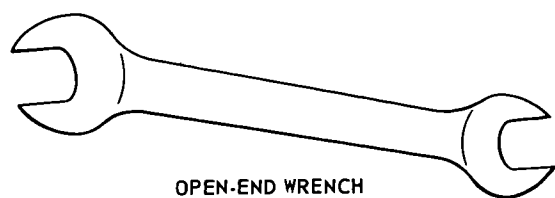
(2) *Box-ends wrenches.* These wrenches are popular tools because of their usefulness in close-quarter areas of work. They are called box-end wrenches because they box or completely surround the nut or object concerned. (fig. 50). Practically all box-end wrenches are made with 12 points so that a 15° pull or swing can be accomplished in close-working areas.

(3) *Combination wrenches.* These wrenches have one box-end and one open-end. When a nut or item is broken loose, it can be removed more quickly with an open-end than with a box-

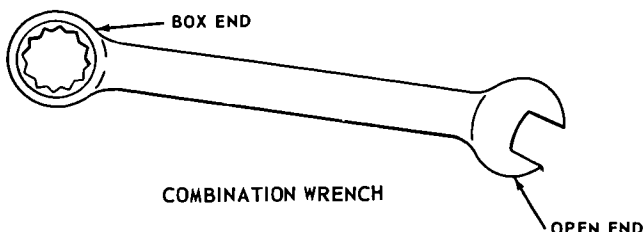
end wrench; the open-end can be positioned and removed quicker during the process.

(4) *Socket wrenches.* These wrenches are made up in two parts: the socket, which is placed over the object to be removed or installed, and the handle which fits into the socket (fig. 50). Several types of handles, extensions, ratchets, and other attachments are available to make it possible to use socket wrenches in almost any location or position. Sockets are made with either fixed or detachable handles. The design of the sockets serve to speed up the turning process.

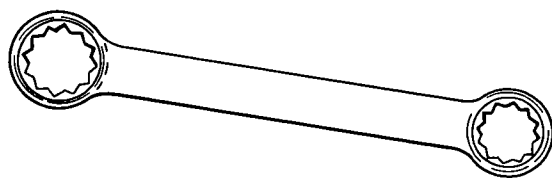
(5) *Adjustable wrenches.* These wrenches come in several sizes, usually determined by the length of the handle. One jaw is fixed, but the other jaw can be positioned as needed by means of a thumb screw or spiral screw-worm adjustment in the handle. The width of the jaws vary from 0 to 1/2 inch or more. The jaws are smooth and are designed similar to the jaws of the open-end wrench. The angle of the opening to the handle is usually 22 1/2°. These features enable the adjustable wrench to do the work of several open-end wrenches. Although versatile, they are not intended to replace the standard open-end, box-end, or socket wrenches. When



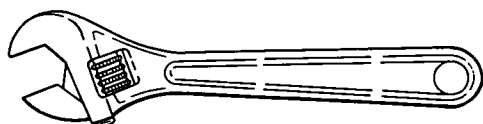
OPEN-END WRENCH



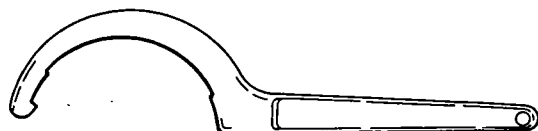
COMBINATION WRENCH



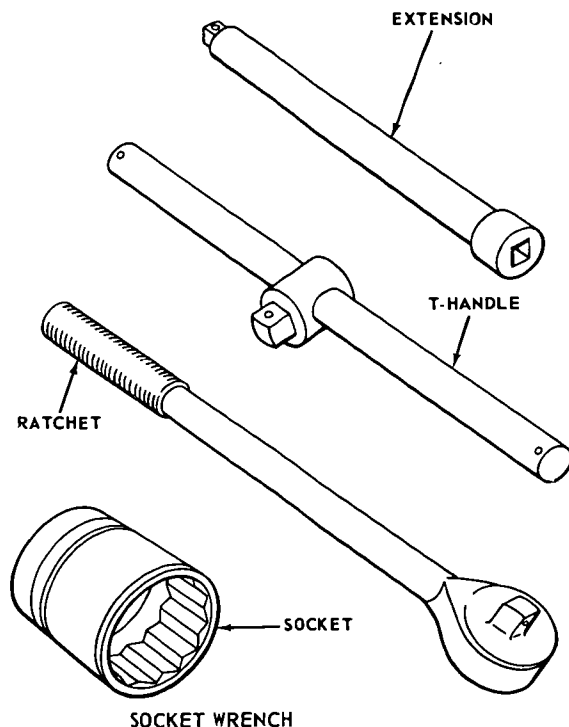
BOX-END WRENCH



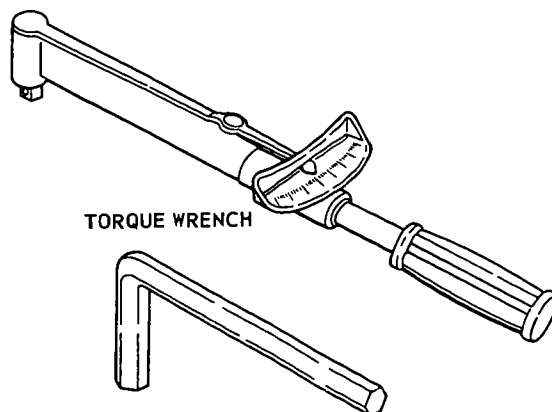
ADJUSTABLE WRENCH



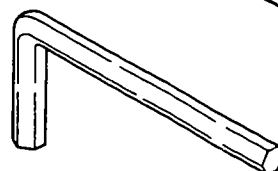
SPANNER WRENCH



SOCKET WRENCH



TORQUE WRENCH



ALLEN WRENCH

Figure 50. Wrenches.

using any adjustable wrench, always exert pull on the side of the handle attached to the fixed jaw of the wrench.

(6) *Special wrenches.* The wrenches that come in the special wrench category are: allen wrenches, spanner wrenches, and torque wrenches. These wrenches are designed for specific use. There are various types in each class of these wrenches.

33. Striking Tools

Hammers and mallets are used by the airframe repairman to form, set up, and attach metal work. Always keep the faces of hammers and mallets smooth and free from dents to prevent marring the work.

a. *Hammers.* Sheet metalworking hammers

are made of metal. They are classified as riveting, stretching, setting, and planishing hammers, and may be used for light bumping, special bumping, or dinging, as applicable (fig. 51).

(1) *Riveting hammers.* These hammers are used for driving rivets and for light chiseling. One end of the hammer head is cross-peened (cross-pointed); the other may have either a square or chamfered face. The obtainable sizes range from 5/8 to 1 1/8 inches, measured across the face.

(2) *Setting hammers.* Setting hammers, sometimes called peening hammers, resemble riveting hammers, except for the peen shape (pointed end). These hammers are used for setting down, clinching, or tucking in the edges of sheet metal. They are particularly useful for

double-seaming lids and bottoms and for making seams and elbows. Setting hammers are made with either square or chamfered faces, the chamfered-face types being preferred.

(3) *Stretching hammers.* Stretching hammers, sometimes called raising hammers, are used for making small depressions or forming concave and convex shapes in soft and semisoft sheet metal. They are available in weights ranging from 20 to 90 ounces.

(4) *Planishing hammers.* These hammers have metal heads with slightly convex faces. They are lighter than stretching hammers, and are used primarily to smooth (or planish) the surfaces of parts which have already been formed. In many cases, the flatface wooden, plastic, or rawhide mallet is used for planishing. In planishing, place the metal on a smooth surface, such as a forming block or stake, and lightly strike the irregularities with the face of the hammer.

b. *Mallets.* Mallets, as shown in figure 52, may be classified as plain-face and stretching. They are generally used for pounding down seams or forming sheet metal over forms or stakes. Since they do not mar the metal as steel hammers do, they are often used for finishing. Plain-face mallets are all-purpose mallets, usually made of hardwood or rawhide and having plain faces. During the forming process, they are best suited for planishing or finishing small dents and/or crimps. Stretching mallets may be made of plastic, hardwood, or hard rubber. They may have bell-shaped, round, or crosspeen ends which are used for stretching (or shrinking), and a plain-faced end which is used for planishing. The bell-shaped and the round-faced mallets are useful for bumping aluminum into form blocks or on a sand bag.

34. Cutting Tools

There are several methods of cutting sheet metal. The airframe repairman will often find it impractical to use power-driven metal cutting tools because of type or location of work to be accomplished. In most cases, it is necessary to use metal cutting hand tools. Among the most frequently used of these tools are: hand shears, bench shears, aviation snips, straight snips, circle snips, hand and breast drills, twist drills, taps and dies, reamers, countersinks and counterbores, files, chisels, burring tools, and hacksaws.

a. *Hand shears.* Hand shears, as shown in figure 53, are made in a variety of shapes and sizes and in two general types, straight (or regular) for straight cutting, and curved for making small circular cuts. The better grade hand shears have tapered blades with inlaid

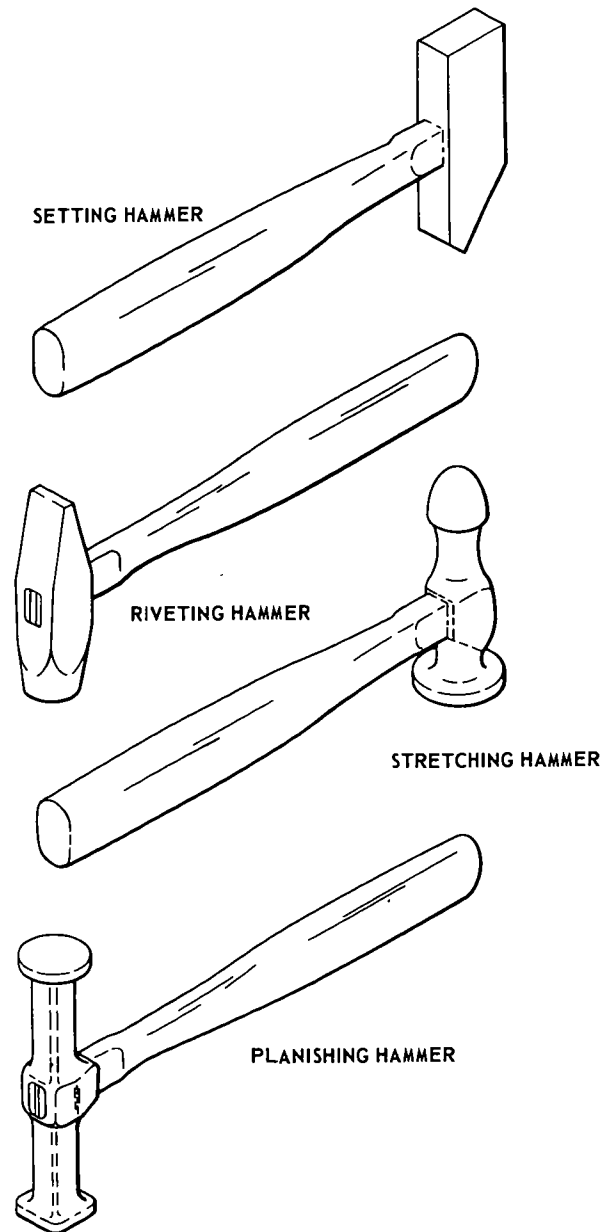


Figure 51. Hammers.

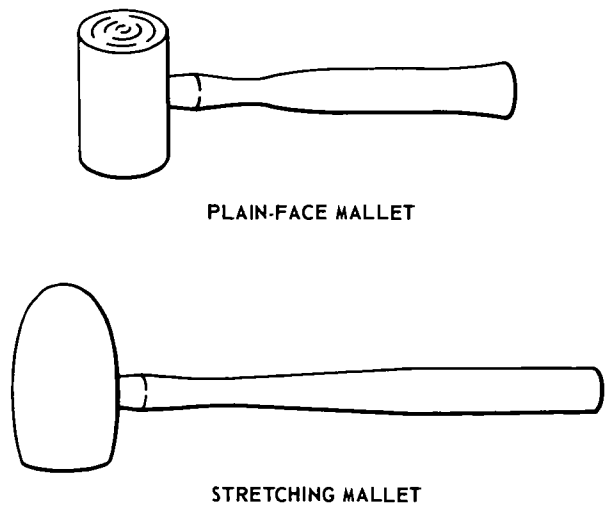


Figure 52. Mallets.

steel cutting edges. The grips, often called bows, are formed to fit the hand and are centered to give a maximum amount of leverage for cutting. Hand shears may be used for cutting metal as heavy as 20 gage.

b. *Bench Shears.* Bench shears are designed for cutting heavy metal (20 to 16 gage) (fig. 53). The lower shank fits into a bench plate while the upper shank can be raised and lowered by hand to execute the cutting operation.

c. *Aviation Snips.* Aviation snips, as shown in figure 54, are designed especially for cutting heat-treated aluminum alloy and stainless steel. They are also adaptable for enlarging small holes. The blades have small teeth on the cutting edges and are shaped for cutting very small circles and irregular outlines. The handles are of the compound-leverage type, making it possible to cut material as thick as 0.051 inch. Aviation snips are available in two styles, those which cut from right to left and those which cut from left to right.

Note. Never use snips as pliers or wire cutters, nor on heavier material than that for which they are intended. Such improper usage may spring the blades and make the snips useless. When cutting, place the upper blade of the snips on the line to be followed and keep the blade perpendicular to the surface of the metal. The waste metal (or the smaller piece) should curl up along the upper edge of the lower blade.

d. *Straight Snips.* Straight snips, as shown in figure 54, are designed for either a right- or left-handed individual. They are used for cutting sheet stock along straight lines and along circles of large diameters.

e. *Circle Snips.* Circle snips, as shown in figure 54, have curved blades and are designed for cutting small inside and outside circles and scrolls. Before a circular opening can be cut in a sheet of metal with circle snips, a starting hole must first be made inside the outline of the desired opening.

f. *Hand and Breast Drills.* The hand and breast drills are the common hand tools for holding and turning twist drills. Holes 1/4 inch diameter or under can be drilled by using a hand drill. This drill, commonly called an *egg beater*, is shown in figure 55 with its big brother, the breast drill, which is designed to take care of tougher jobs.

g. *Twist Drills.* The word *drill* usually refers to a part which is inserted in a drilling machine and turned to make a hole. Carpenters call it the *bit*. In metalwork, the name *bit* is not used. The word *drill* may mean the *bit*, or it may mean the machine into which the *bit* fits. If the machine is power driven, drill may mean the power drill. The bit is called a *twist drill*, the hand machine is called the *hand drill*, and the power-driven

portable machine is called a *portable power drill* (electric or air driven). The *drill press*, usually electrically driven, is not portable. Since these names are clear cut and prevent confusion, they should be used. General information for twist drills is shown in figure 56. Twist drills are made of carbon steel or high-speed alloy steel. Carbon steel drills are satisfactory for general work and are used extensively because they are less expensive. The more expensive high-speed twist drills are used for the tough materials such as stain-

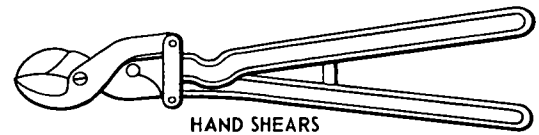
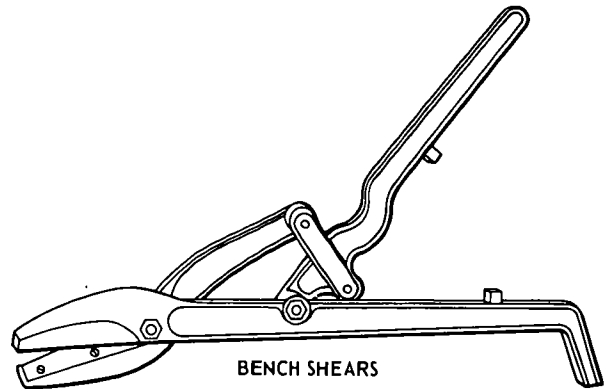


Figure 53. Shears.

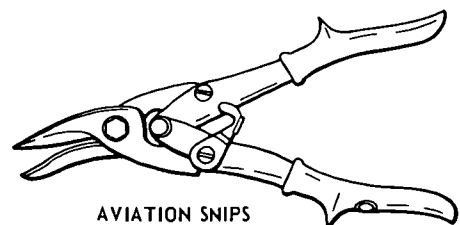
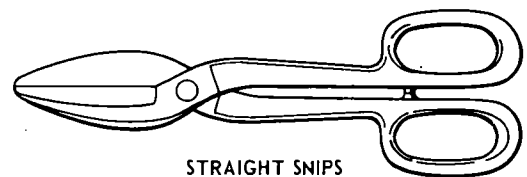
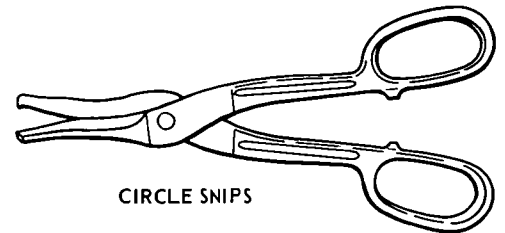


Figure 54. Snips.

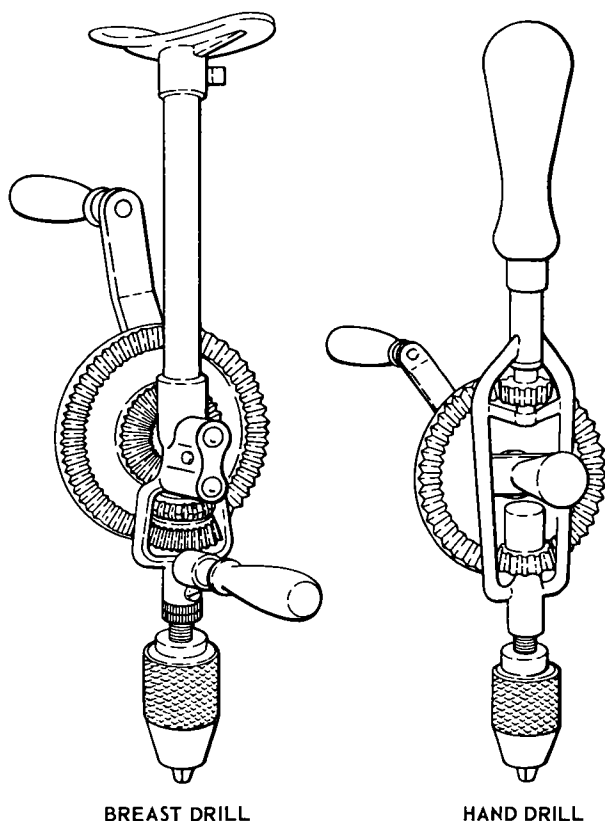


Figure 55. Hand and breast drills.

less steels. High-speed twist drills will cut even though they are hot; however, they should be cooled in still air. If they are cooled quickly, as in water, they have a tendency to crack. The chuck (the part into which the twist drill is clamped) may mar the shank of the twist drill so badly that the drill size cannot be determined. In this case, use of micrometer or drill gage to determine the proper size of the twist drill. When the material being worked is comparatively soft, the hand drill will be satisfactory for drilling. The hand drill has a chuck which will receive a twist drill up to 1/4 inch in diameter; this size is large enough for most of the drilling the airframe repairman will accomplish. In drilling a hole, locate the exact center of the hole to be drilled; then, using a center punch, sink a mark deep enough to receive the tip of the drill. (Be careful not to dimple the material by striking the center punch too hard.) Fasten the work securely, place the tip of the drill into the center punch mark, and begin drilling. Make certain to keep the drill at right angles to the surface of the work throughout the operation. Ease the pressure on the drill the instant the drill breaks through the other side, and continue drilling until the hole is finished.

(1) *Twist drill sizes.* Twist drill sizes are expressed in terms of numbers, letters and in-

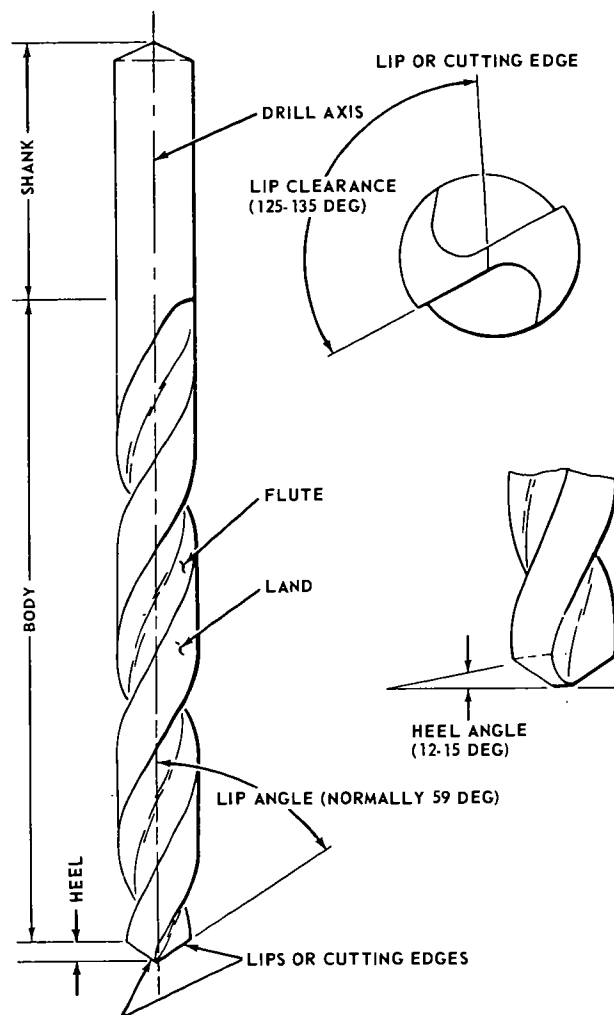


Figure 56. Twist drill nomenclature.

ches or fractions of an inch. Twist drills are numbered from 1 through 80 and are lettered from A through Z as shown in table 23. The size is stamped on the shank of the twist drill.

Note. Numbered twist drills decrease in size from 1 to 80. Lettered twist drills increase in size from A to Z.

(2) *Sharpening twist drills.* The twist drill should be sharpened at the first sign of dullness. For most drilling that the airframe repairman will do, a twist drill with a cutting angle of 118° (59° on either side of center) will be sufficient; however, when drilling soft metals, a cutting angle of 90° may be more efficient. The following paragraphs describe a typical procedure for sharpening twist drills.

(a) Adjust the tool rest of a grinder to a convenient height for resting the back of the hand, then turn on grinder.

Warning: Always wear goggles when using a grinding wheel.

(b) Hold the twist drill between the thumb and index finger of the right or left hand.

Table 23. Twist Drill Sizes

Size	Decimal equivalent	Size	Decimal equivalent	Size	Decimal equivalent	Size	Decimal equivalent
$\frac{1}{2}$	0.5000	G	0.2610	23	0.1540	$\frac{1}{16}$	0.0625
$\frac{3}{16}$	0.4844	F	0.2570	24	0.1520	53	0.0595
$\frac{15}{32}$	0.4687	E- $\frac{1}{4}$	0.2500	25	0.1495	54	0.0550
$\frac{29}{64}$	0.4531	D	0.2460	26	0.1470	55	0.0520
$\frac{7}{16}$	0.4375	C	0.2420	27	0.1440	$\frac{3}{16}$	0.0469
$\frac{27}{64}$	0.4219	B	0.2380	$\frac{9}{64}$	0.1406	56	0.0465
Z	0.4130	$\frac{15}{64}$	0.2344	28	0.1405	57	0.0430
$\frac{13}{32}$	0.4062	A	0.2340	29	0.1360	58	0.0420
Y	0.4040	1	0.2280	30	0.1285	59	0.0410
X	0.3970	2	0.2210	$\frac{1}{8}$	0.1250	60	0.0400
$\frac{25}{64}$	0.3906	$\frac{7}{32}$	0.2187	31	0.1200	61	0.0390
W	0.3860	3	0.2130	32	0.1160	62	0.0380
V	0.3770	4	0.2090	33	0.1130	63	0.0370
$\frac{3}{8}$	0.3750	5	0.2055	34	0.1110	64	0.0360
U	0.3680	6	0.2040	35	0.1100	65	0.0350
$\frac{23}{64}$	0.3594	$\frac{13}{64}$	0.2031	$\frac{7}{64}$	0.1094	66	0.0330
T	0.3580	7	0.2010	36	0.1065	67	0.0320
S	0.3480	8	0.1990	37	0.1040	$\frac{1}{32}$	0.0312
$\frac{11}{32}$	0.3437	9	0.1960	38	0.1015	68	0.0310
R	0.3390	10	0.1935	39	0.0995	69	0.0292
Q	0.3320	11	0.1910	40	0.0980	70	0.0280
$\frac{21}{64}$	0.3281	12	0.1890	41	0.0960	71	0.0260
P	0.3230	$\frac{3}{16}$	0.1875	$\frac{3}{32}$	0.0937	72	0.0250
O	0.3160	13	0.1850	42	0.0935	73	0.0240
$\frac{5}{16}$	0.3125	14	0.1820	43	0.0890	74	0.0225
N	0.3020	15	0.1800	44	0.0860	75	0.0210
$\frac{19}{64}$	0.2969	16	0.1770	45	0.0820	76	0.0200
M	0.2950	17	0.1730	46	0.0810	77	0.0180
L	0.2900	$\frac{11}{64}$	0.1719	47	0.0785	78	0.0160
$\frac{9}{32}$	0.2812	18	0.1695	$\frac{5}{64}$	0.0781	$\frac{1}{64}$	0.0156
K	0.2810	19	0.1660	48	0.0760	79	0.0145
J	0.2770	20	0.1610	49	0.0730	80	0.0135
I	0.2720	21	0.1590	50	0.0700		
H	0.2660	22	0.1570	51	0.0670		
$\frac{17}{64}$	0.2656	$\frac{5}{32}$	0.1562	52	0.0635		

Grasp body of the twist drill near the shank with the other hand.

(c) Place the hand on the tool rest with the centerline of the twist drill making a 59° angle with the cutting face of the grinding wheel. Slightly lower the shank end of the twist drill. See details (A), (B), and (C), figure 57.

(d) Slowly place the cutting edge of the twist drill against the grinding wheel. Gradually lower the shank of the twist drill and at the same time turn the twist drill in a clockwise direction. Maintain pressure against the grinding surface only until the heel of the twist drill is reached.

(e) Check the results of grinding with a gage to determine whether or not the lips are the same length and at a 59° angle. See detail (D), figure 57.

(f) The heel angle of the twist drill should be 12° to 15°, as shown in detail (E), figure 57. Insufficient heel angle will cause the drill to lose its effectiveness.

h. Taps and Dies. Taps and dies are used for cutting threads in material. Taps are used to cut inside threads (female threads). Three types of taps are taper, plug, and bottoming, as shown in figure 58. Dies are used to cut outside threads as on a rod, bolt, or pipe. They are classified as solid, adjustable-split, and pipe.

i. Reamers. Reamers are used to smooth and enlarge holes to exact size. Hand reamers have square end shanks so they can be turned with a tap wrench or similar handle. A hole that is to be reamed to exact size must be drilled about 0.003 to 0.007 inch undersize. A cut that removes more than 0.007 inch places too much load on the reamer and should not be attempted. Reamers as shown in figure 59 are made of either carbon tool steel or high-speed steel. The cutting blades of a high-speed steel reamer lose their original keenness sooner than those of a carbon steel reamer; however, after the first superkeenness is gone, they are still serviceable. The high-speed reamer usually lasts much longer than the car-

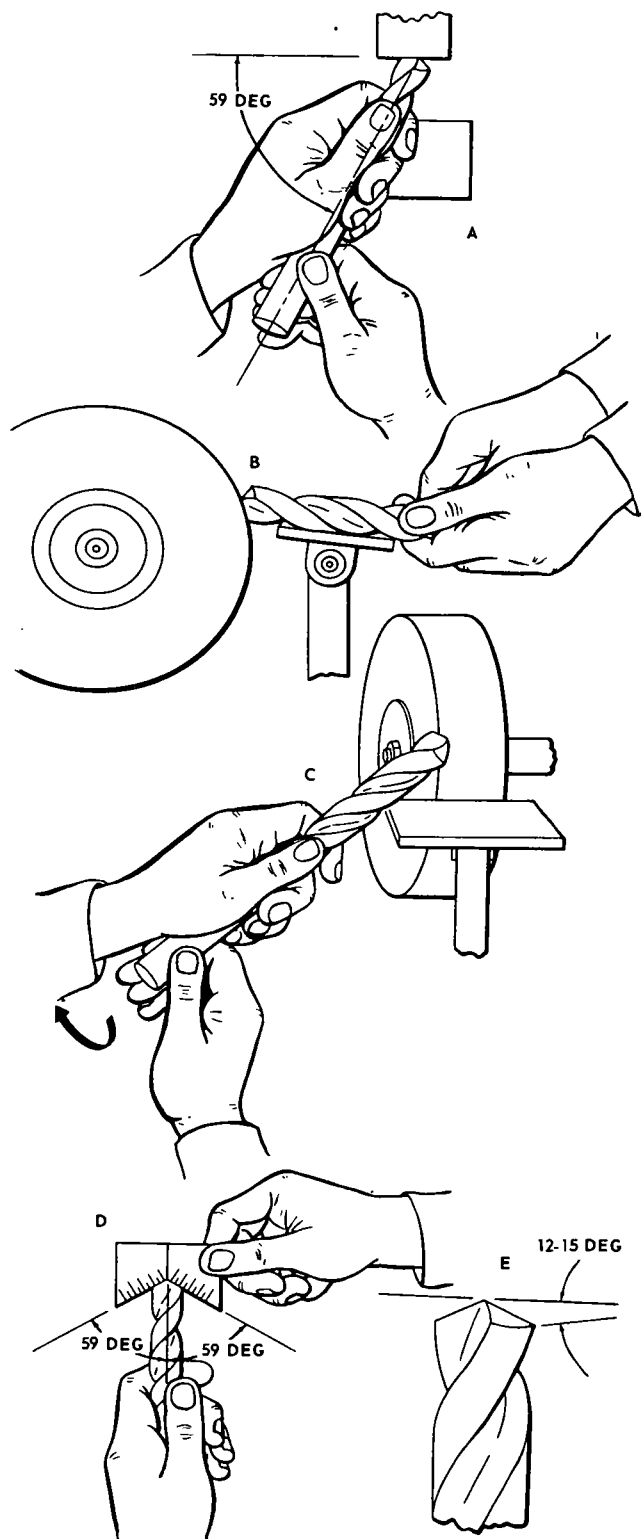


Figure 57. Drill sharpening guide.

bon steel type. Reamer blades are hardened to the point of being brittle and must be handled carefully to avoid chipping them. When reaming a hole, rotate the reamer in the cutting direction only. Turn the reamer steadily and evenly to prevent chattering or marking and scoring of the hole walls. Reamers are available in any

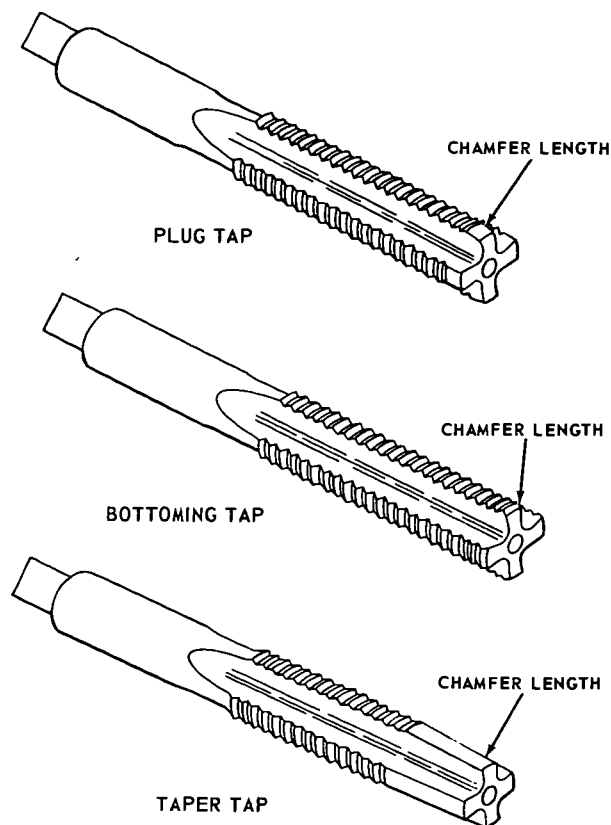


Figure 58. Types of taps.

standard size. The straight flute reamer is less expensive than the spiral flute reamer, but the spiral type has less tendency to chatter. Both types are tapered for a short distance back to the point to aid starting. Bottoming reamers have no taper and are used to complete the reaming of blind holes. For general use, an expansion reamer is the most practical. This type is furnished in standard sizes from 1/4 inch to 1 inch, increasing in diameter by thirty-seconds. Each reamer has a maximum expansion of 1/32 inch. Taper reamers, both hand and machine operated, are used to smooth and true tapered holes and recesses.

j. Countersinks and Counterbores. Countersinks, as shown in figure 60, and counterbores, as shown in figure 61, are used to enlarge a portion of a drilled hole. Countersinks enlarge the drilled hole in a tapered fashion; counterbores enlarge the drilled hole to a given depth, using a pilot to keep the center true.

k. Files. The file, as shown in figure 62, is the most simple yet the most misused and improperly cared for cutting tool that the airframe repairman uses. Most files are made of high-grade tool steels that are hardened and tempered. Files are manufactured in a variety of shapes and sizes. They are known either by the cross section, the general shape, or by their par-



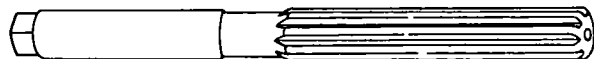
TAPER REAMER (WITH STRAIGHT FLUTES)



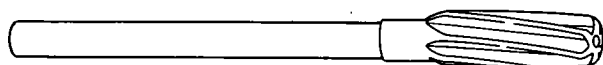
TAPER REAMER (WITH SPIRAL FLUTES)



EXPANSION REAMER (WITH STRAIGHT FLUTES)



BOTTOMING REAMER (WITH STRAIGHT FLUTES)



HIGH-SPEED REAMER (WITH SPIRAL FLUTES)

Figure 59. Reamers.

ticular use. The cuts of files must be considered when selecting them for various types of work and materials. Files are used by the airframe repairman to square ends, file rounded corners, remove burrs and slivers from metal, straighten uneven edges, file holes and slots, and smooth rough edges. Files have three distinguishing features—length (measured exclusive of the tang), type or name (which has reference to the relative coarseness of the teeth), and cut. Files are usually made in two types of cuts, single-cut and double-cut. The single-cut file has a single row of teeth extending across the face at an angle of 65° to 85° with the length of the file. The size of the cuts depends on the coarseness of the file. The double-cut file has two rows of teeth which cross each other. For general work, the angle of the first row is 40° to 45° . The first row is generally referred to as *over-cut* and the second row as *up-cut*, the up-cut being somewhat finer and not so deep as the over-cut.

(1) *File types.* The files most generally used are—

(a) *Hand files.* These files are parallel in width and tapered in thickness. They have one safe edge (smooth edge) which permits filing in corners and on other work where a safe

edge is required. Hand files are double-cut and are used principally for finishing flat surfaces and similar work.

(b) *Flat files.* These files are slightly tapered toward the point in both width and thickness. They cut on both edges as well as on the sides and are the most common files in use. Flat files are double-cut on both sides and single-cut on both edges.

(c) *Mill files.* These files are usually tapered slightly in thickness and in width for about one-third of their length. The teeth are ordinarily single-cut. These files are used for drawfiling and, to some extent, for filing soft metals.

(d) *Square files.* These files may be tapered or blunt and are double-cut. They are used principally for filing slots and key seats and for surface filing.

(e) *Round or rattail files.* These files are circular in cross section and may be either tapered or blunt and single- or double-cut. They are used principally for filing circular openings or concave surfaces.

(f) *Triangular and three-square files.* These files are triangular in cross section. Triangular files are single-cut and are used for filing the gullet between saw teeth. Three-square files are double-cut and may be used for filing internal angles, clearing out corners, and filing taps and cutters.

(g) *Half-round files.* These files cut on both the flat and round sides and may be single- or double-cut. Their shape permits them to be used where other files would be unsatisfactory.

(h) *Lead float files.* These files are especially designed for use on soft metals, are single-cut, and are made in various lengths.

(2) *Methods of use.* The following methods are recommended for using files.

(a) *Crossfiling.* Before attempting to use a file, place a handle on the tang of the file; this is essential for proper guiding and safe use. In moving the file endwise across the work (commonly known as cross-filing), grasp the handle so that its end fits into and against the fleshy part of the palm, with the thumb lying along the top of the handle in a lengthwise direction. Grasp the end of the file between the thumb and first two fingers. To prevent undue wear, relieve the pressure during the return stroke. Hold work surfaces that are narrow near the vise jaws to prevent vibration. If a surface is straight, place it parallel to the top of the vise.

(b) *Drawfiling.* A file is sometimes used by grasping it at each end, crosswise to the work, then moving it lengthwise with the work. When done properly, work may be finished some-

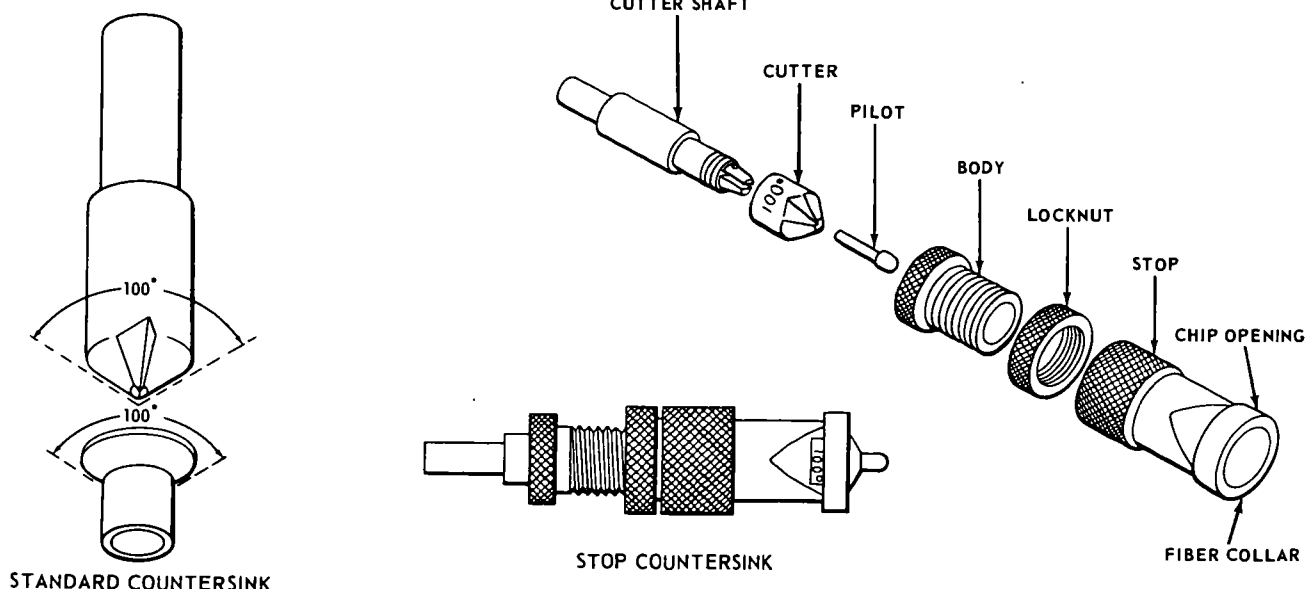
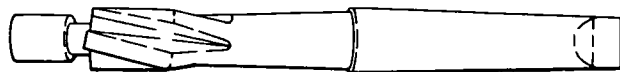


Figure 60. Countersinks

what finer than when crossfiling with the same file. In drawfiling, the teeth of the file produce a shearing effect. To accomplish this shearing effect, the angle at which the file is held with respect to its line of movement varies with different files, depending on the angle at which the teeth are cut. Pressure should be relieved during the back stroke, as in cross-filing.

(c) *Rounding corners.* The method used in filing a rounded surface depends upon the width and radius of the rounded surface. If the surface is narrow in width or only a portion of a surface is to be rounded, start the forward stroke of the file with the point of the file inclined downward at approximately a 45° angle. Using a rocking chair motion, finish off the stroke with the heel of the file near the curved surface. This method allows use of the full length of the file.



COUNTERBORE
Figure 61. Counterbore.

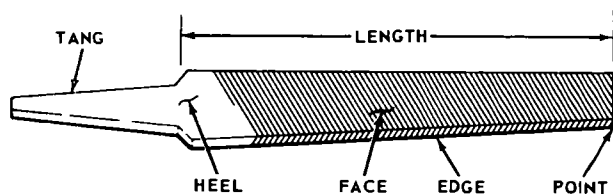


Figure 62. File.

tal produces burrs or slivers. These must be removed to avoid personal injury and to prevent scratching and marring of parts that are to be assembled. Burrs and slivers will prevent parts from fitting properly and should always be removed from the work as a matter of habit.

(3) *Cleaning files.* Particles of metal collect between the teeth of a file and may make deep scratches as the file is passed over the work. When these particles of metal are lodged too firmly between the teeth and cannot be removed by tapping the edge of the file, remove them with a file cleaner brush or wire brush as shown in figure 63. Draw the brush across the file so that the bristles pass down the gullet between the teeth.

1. *Chisels.* Chisels are usually made of 8-sided tool steel bar stock, carefully hardened and tempered. The cutting edge is slightly convex. Chisels are made in several shapes, as shown in figure 64. The chisel can be used in restricted

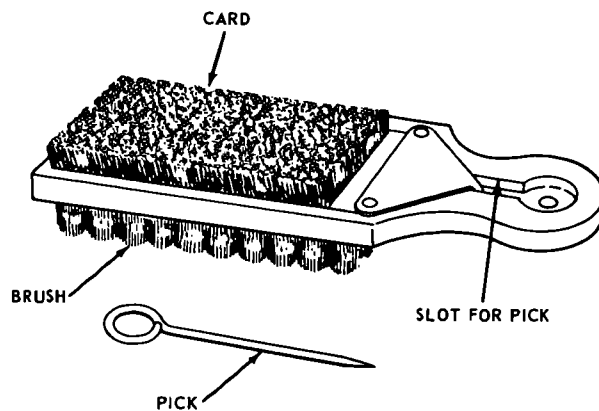


Figure 63. File cleaner brush.

(d) *Removing burred or slivered edges.* Practically every cutting operation on sheet me-

areas and for such work as shearing off rivets, smoothing castings, or splitting nuts from bolts. The cutting edge of a chisel will cut any metal softer than itself and is designed so that the center portion will receive the shock while cutting and protect the weaker corners. The point angle should be 60° to 70° for general use, such as cutting wire, straps, bars, and rods. Chisels are used according to design of cutting edge and type work involved.

m. Burring Tools. Burring tools or bearing scrapers are used to remove burrs or rough edges from metal after it has been cut to approximate size. The burring process is shown in figure 65. Files can also be used to dress the metal to the layout line. Use care when using these tools, as their edges are hard and will scratch softer material.

n. Hacksaws. The common hacksaw has a blade, a frame, and a handle. The handle can be obtained in two styles, pistol grip and straight, as shown in figure 66. The frame is designed to hold the blade at each end by pins. An adjusting screw on one end of the frame applies lock and tension on the blade and holds the blade firmly in place. Always position the blade in the hacksaw frame with the teeth pointing forward, away from the handle.

(1) *Hacksaw blade.* Hacksaw blades are made of high-grade tool steel or tungsten and are available in sizes from 6 to 16 inches. The 10-inch blade is most commonly used. There are two types, the all-hard blade and the flexible blade. In flexible blades, only the teeth are hardened. Selection of the best blade for the job involves finding the right type and pitch. An all-hard blade is best for sawing brass, tool steel, cast iron, and heavy cross-section materials. A flexible blade is usually best for sawing hollow shapes and metals having thin cross section. The pitch of a blade indicates the number of teeth per inch. Pitches of 14, 18, 24, and 32 teeth per inch are available. A blade with 14 teeth per inch is preferred when cutting machine steel, cold-rolled steel, or structural steel. A blade with 18 teeth per inch is preferred for solid stock aluminum, bearing metal, tool steel, and cast iron. Use a blade with 24 teeth per inch when cutting thick-walled tubing, pipe, brass, copper, channel, and angle iron. Use a 32-teeth-per-inch blade for cutting thin-walled tubing and sheet metal.

(2) *Methods of use.* When using a hacksaw, observe the following procedures:

(a) Select an appropriate saw blade for the job.

(b) Assemble the blade in the frame so

that the teeth point in the direction away from the handle.

(c) Adjust tension of the blade in the frame to prevent the saw from buckling and drifting. Clamp the work in a vise in such a way that it will provide as much bearing surface as possible and will engage the greatest number of teeth.

Note. The use of soft removable jaw covers on the vise will prevent marring a finished surface. To prevent work from springing, place the work so that the saw will not cut more than ¼ inch away from vise jaws.

(d) Indicate the starting point by nicking the surface with the edge of a file to break any sharp corner that might tend to strip the teeth. This mark will also aid in starting the saw at the proper place.

(e) Hold the saw at an angle that will keep at least two teeth in contact with the work at all times. Start the cut with a light, steady, forward stroke just outside the cutting line. At the end of the stroke, relieve the pressure and draw the blade back. (The cut is made on the forward stroke.)

(f) After the first few strokes, make each stroke as long as the hacksaw frame will allow. This will prevent the blade from overheating. Apply just enough pressure on the forward stroke to cause each tooth to remove a small amount of metal. The strokes should be long and steady with a speed of not more than 40 to 50 strokes per minute.

(g) After completing the cut, remove chips from the blade, loosen tension on the blade, and return the hacksaw to its proper place.

35. Punches

There are several types of punches, such as hollow punches, solid punches, leverage-type punches, and nibblers. Punches are usually made of carbon steel and tempered at both ends. They are used to cut metal, locate centers, start points for drilling, punch holes, transfer hole locations with patterns, and remove rivets, bolts, or pins. Punches are classified according to their use and point design. Punches used by airframe repairman are as follows:

a. Hollow Punch. The hollow punch has a point designed to cut holes in thin, soft metal (fig. 67). The rim of the point is sized to fit hole requirements. The point is hollow with a thin wall which is the cutting point. A circle is inscribed around a center mark as required for a hole, and a hollow punch the size of the hole is selected. A solid tap on top of the punch will cut out the inscribed hole.

b. Solid Punches. Solid punches are classified according to the shape of their points. Some

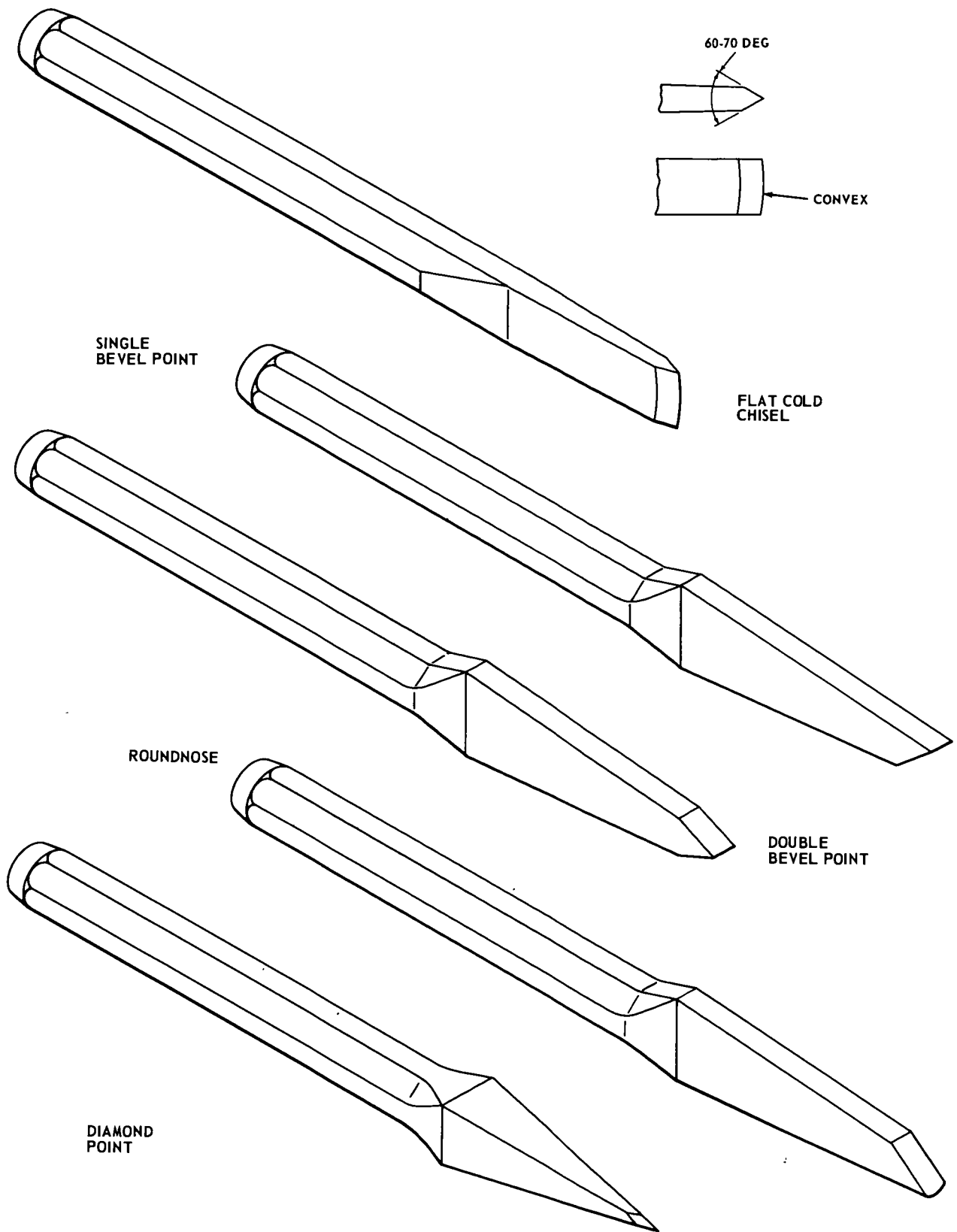
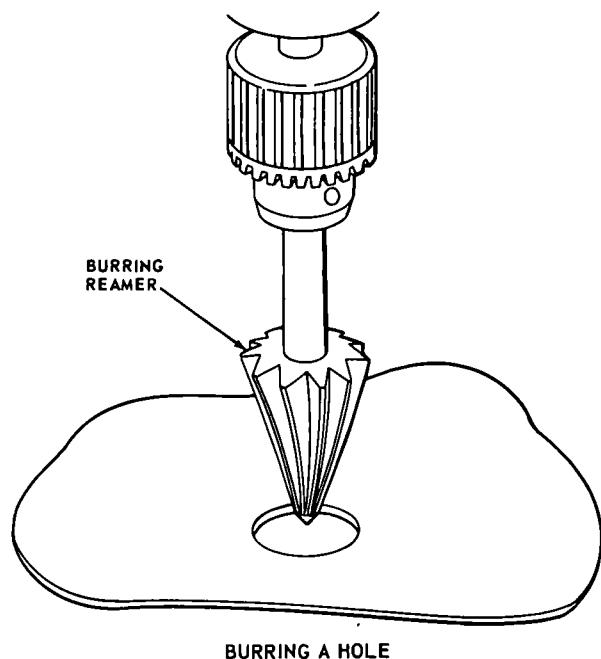
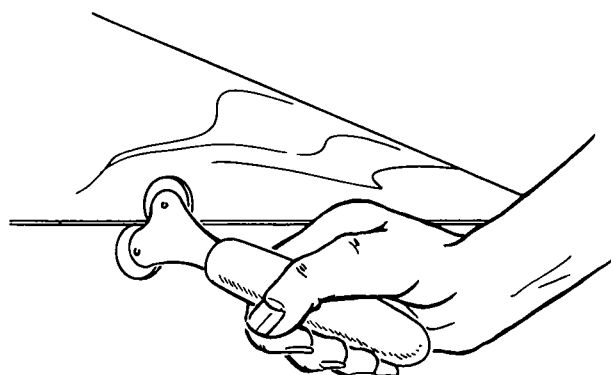


Figure 64. Chisels.



BURRING A HOLE



BURRING STRAIGHT EDGE

Figure 65. Burring process.

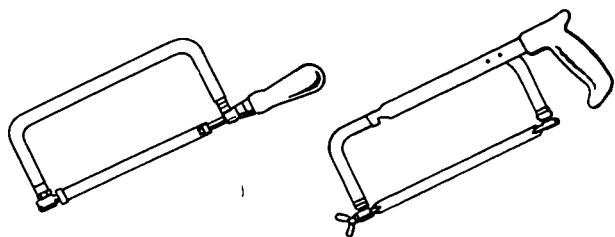
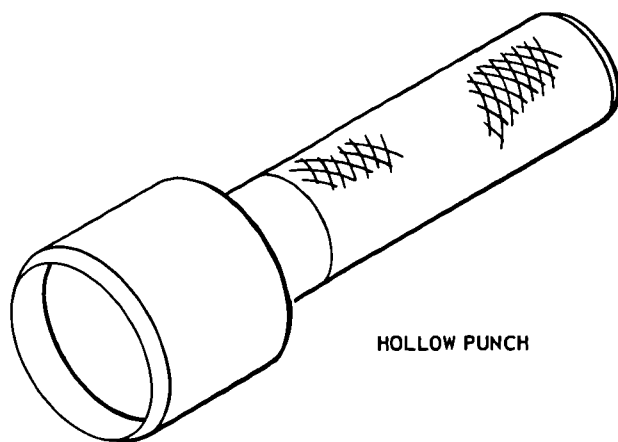


Figure 66. Hacksaws.

solid punches are shown in figure 68 and the most generally used solid punches are covered in the following steps.

(1) *Prick punch.* Prick punches are used to place reference marks on metal (fig. 68). This punch is often used to transfer dimensions from a paper pattern directly on the metal. To do this, first place the paper pattern directly on the metal. Then go over the outline of the pattern with the prick punch, tapping it lightly with a small hammer and making slight inden-



HOLLOW PUNCH

Figure 67. Hollow punch.

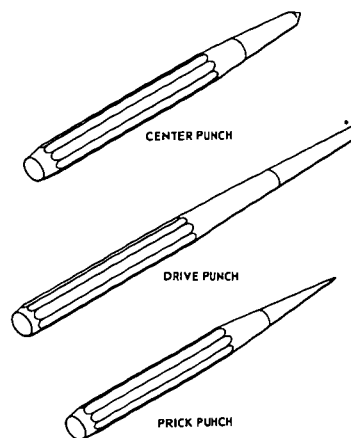


Figure 68. Solid punches.

tations on the metal at the major points on the drawing. These indentations can then be used as reference marks for cutting or folding the metal. A prick punch should never be struck a heavy blow with a hammer, as it may bend the punch or cause excessive damage to the material being worked. Never use a prick punch to remove objects from holes, as the point of the punch will spread the object and cause it to bind even more.

(2) *Center punch.* Large indentations in metal, such as are necessary to start a twist drill, are made with a center punch (fig. 68). It should never be struck with enough force to dimple the material around the indentation or to cause the metal to protrude through the other side of the sheet. A center punch has a heavier body than a prick punch and is ground to a point with an angle of about 60°. Never use a center punch to remove objects from holes, as the point of the punch will spread the object and cause it to bind even more.

(3) *Automatic center punch.* The automatic center punch contains a mechanism which automatically strikes a blow of the required force when the punch is in the exact position desired

by the operator and is pushed forward by hand pressure. The punch has an adjustable cap for regulating the stroke; the point is removable for regrinding and/or replacement.

Note. Never strike an automatic center punch with a hammer.

(4) *Drive punch.* The drive punch, which is often called a tapered punch, is used for driving out damaged rivets, pins, and bolts which sometimes bind in holes (fig. 68). The drive punch is therefore made with a flat face instead of a point. The size of the punch is determined by the width of the face, which is usually 1/8 to 1/4 inch.

(5) *Pin punch.* Pin punch, often called drift punches, are similar to drive punches and are used for the same purposes. The difference in the two is that the sides of a drive punch taper all the way to the face, while the pin punch has a straight shank. The points of pin punches are sized in thirty-seconds of an inch and range from 3/16 to 3/8 inch in diameter. In general practice, a pin or bolt which is to be driven out is usually started and driven with a drive punch until the sides of the punch touch the side of the hole. A pin punch is then used to drive the pin or bolt the rest of the way out of the hole. Stubborn pins may be started by placing a thin piece of scrap copper, brass, or aluminum directly against the pin and then striking it with a heavy hammer until the pin begins to move.

(6) *Transfer punch.* The transfer punch is usually about 4 inches long and has a point that is tapered and then turned straight for a short distance in order to fit a drill locating hole in a template. The tip has a point similar to that of a prick punch. As its name implies, the transfer punch is used to transfer the location of holes through the template or pattern to the material.

c. Leverage-Type Punches. Leverage-type punches have largely taken the place of hollow punches. These leverage-type punches are handy tools around the sheet metal shop, as they afford a means of punching clean holes. They will also punch heavier sheets with less time and labor. There are a number of leverage-type punches manufactured; one type is shown in figure 69. The punches and dies have a range of sizes and are easily changed to suit most punching jobs. Make certain the punches and dies do not get mixed up, because a punch will probably break one, if not both, of the parts if forced into a smaller size die. Keep the working parts of the tool well lubricated to insure ease of operation. Most punches have a gage attached which consists of a guide and an adjustable scale. The scale

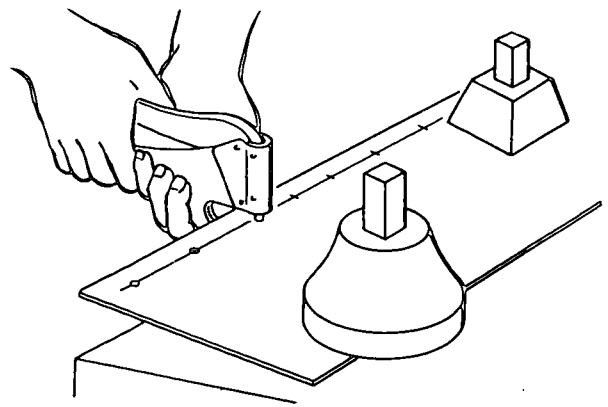


Figure 69. Using a leverage-type punch.

graduation on the guide mark indicates the depth of the throat in inches; that is, the distance from the edge of the sheet metal to the center of the hole. The gage is not generally used because a center punch will first be used to mark the position of the holes to be punched. This punch mark can then be easily felt with the centering point on the hand punch. Never use a punch on material that is beyond the capacity of the punch. Changing dies in a leverage-type punch is a relatively simple matter. The bottom die is made with threads cut around the outside. This die screws into the lower tip of the throat jaws by means of a slot. By placing a screwdriver in this slot, the die can be moved in or out as the need arises. The punch can be removed by taking out the pin or screw which is located just forward of the lower handle; then, by pushing the punch holder forward, the punch die is easily removed. To replace the punch, reverse the procedure.

d. Nibblers. Hand-operated, pneumatic-driven nibblers can be used to cut thin gage metal. Nibblers have features similar to the riveting hammer. To cut metal or punch out material, scribe a line and drill a starting hole. Position the lower jaw of the nibbler in the starting hole and operate the tool. As the tool is operated and drawn over the material, a series of overlapping holes are punched which form a continuous cut. Refer to paragraph 40f, for additional information on nibblers.

36. Screwdrivers

The screwdriver, classified by its blade length and design, is made for loosening or tightening screws or screwhead bolts. It should not be used as a prybar or chisel. The parts of a screwdriver are the handle, shank, and blade, and the sizes of these parts are in proportion to the overall length. There are five types of screw-

drivers: standard, phillips, reed and prince, offset, and ratchet (fig. 70).

a. Standard Screwdriver. The standard screwdriver, as shown in figure 70, is the most popular screwdriver. Most standard screwdrivers range from 3 to 12 inches in length, although they may be obtained in shorter and longer lengths. The length is measured from the tip of the blade to the tip of the handle. It is important to select the correct size screwdriver so that the thickness of the blade fits properly into the screw slot.

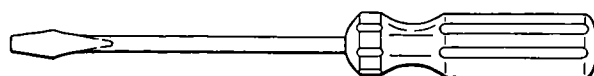
b. Phillips Screwdriver. The phillips screwdriver is made with a specially shaped blade that fits phillips cross-slot screws. The heads of these screws have a 4-way slot that prevents the screwdriver from slipping. Three standard sizes of phillips screwdrivers handle a wide range of screw sizes. A standard screwdriver should not be used on phillips-head screws.

c. Reed and Prince Screwdriver. The reed and prince screwdriver is similar to the phillips screwdriver, however they should not be confused, as the tip is different. These screwdrivers are manufactured in 3- to 8-inch sizes.

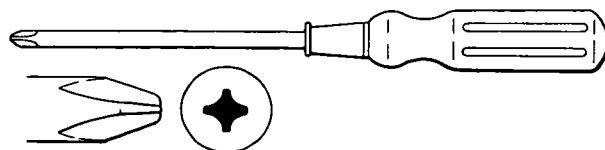
d. Offset Screwdriver. The offset screwdriver is designed to be used in tight places when an ordinary screwdriver cannot be used. It is somewhat unhandy to use, as it is difficult to keep enough pressure on it to prevent slipping. The blades at either end are placed at right angles to each other. They are set in this manner to enable turning a screw a quarter turn, change ends of the screwdriver, and then make another quarter turn.

e. Ratchet Screwdriver. The ratchet screwdriver, sometimes called the spiral screwdriver, is fast acting in that it turns the screw when the handle is pulled back and then pushed forward. It can be set to turn the screw either clockwise or counterclockwise, or it can be locked in position and used as a standard screw-

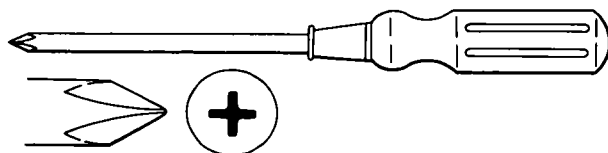
driver. Various blade sizes can be fitted into the chuck. The ratchet screwdriver is not a heavy duty tool and should be used only for light work.



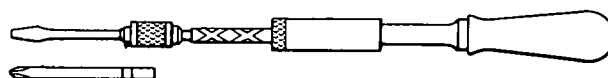
STANDARD SCREWDRIVER



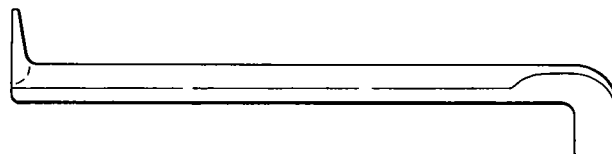
PHILLIPS SCREWDRIVER



REED AND PRINCE SCREWDRIVER



RATCHET SCREWDRIVER



OFFSET SCREWDRIVER

Figure 70. Screwdrivers.

Section III. SPECIAL TOOLS AND DEVICES

37. Dolly Blocks, Stakes, and Bench Plates

The airframe repairman does a lot of work with special tools and devices that have been developed to make job performance faster, simpler, and better. These special tools and devices include dolly blocks, stakes, bench plates, and various type blocks and sandbags used as supports in the bumping and forming process.

a. Dolly Blocks. Dolly blocks, sometimes called anvils, are iron body blocks with smooth surfaces. Dolly blocks as shown in figure 71 have various shapes which make them easily adapt-

able for many uses while repairing aircraft metal. Dolly blocks are designed to be held by hand and against the surface to be worked.

b. Stakes and Benchplates. Stakes are special type dolly blocks having various finished shapes which are used with a benchplate as shown in figure 72. Most stakes have machined, polished surfaces which have been hardened. Do not use stakes to back up material when chiseling or when using any similar cutting tool, as this will deface the surfaces of the stakes and make them

useless for finish work. Stakes and their applications are covered in the following procedures:

(1) *Square stakes.* Three types of square stakes for general sheet metal work are—the common square stake, the coppersmith square stake, and the bevel-edge square stake. The coppersmith square stake has one rounded end while the bevel-edge square stake is offset, permitting a greater variety of applications.

(2) *Double-seaming stakes.*

(a) *Simple.* The simple double-seaming stake consists of two horns with elongated heads. It is used as a support when laying down double seams on small cylindrical objects.

(b) *Fourhead.* The fourhead double-seaming stake has two shanks and four interchangeable heads. This arrangement permits it to be used for several different positions and conditions. It is suitable for all kinds of riveting and for double seaming of large objects.

(3) *Roundhead stake.* The roundhead stake is not used extensively; however, its curved head makes it suitable for forming curved and irregularly shaped objects.

(4) *Bottom stake.* The bottom stake has a flared end and is used for dressing down an object having a burred or flanged circular bottom.

(5) *Needlecase stake.* The needlecase stake has a round, tapered horn for forming small rings and tubular objects, and a heavier rectangular horn on which square work can be formed.

(6) *Conductor stake.* The conductor stake has two cylindrical horns of different diameters. It is used for forming, seaming, and riveting pipes and elbows, especially those with small diameters.

(7) *Candlemold stake.* The candlemold stake has a horn of rather large diameter on one end and a long, tapered horn on the other. The larger horn is used for general purposes, and the smaller one for reshaping and tube forming.

(8) *Hatchet stake.* The hatchet stake has a beveled horizontal bar. It is used for making straight bends and for folding and bending edges; it is also used for flanging and dovetailing operations.

(9) *Creasing stake.* The creasing stake has a tapered horn on one end for shaping conical objects. A creased mandrel on the other end permits bending, wiring, and turning operations.

(10) *Beakhorn stake.* A round, tapered horn on one end, and a square, tapered horn on the other, make the beakhorn stake adaptable for general sheet metal work, shaping, and riveting round and square objects.

(11) *Blowhorn stake.* The blowhorn stake has a large tapered end, called an apron, which

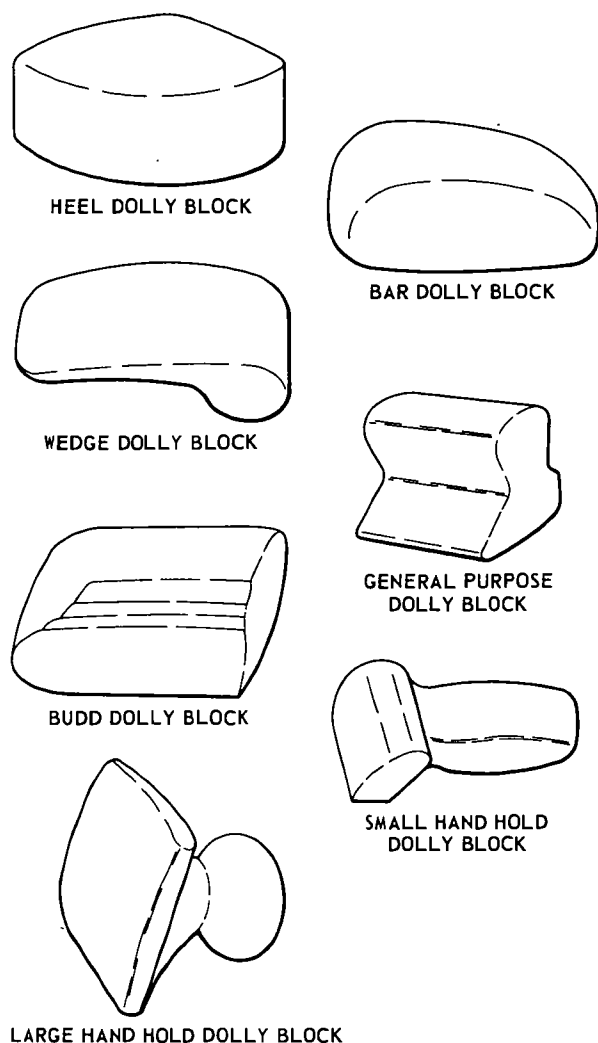


Figure 71. Dolly blocks.

is used for shaping objects with abrupt tapers, such as funnels. The other end of the stake is round and has a long narrow taper for forming slightly tapered objects. It can also be used to form metal or wire into rings of small diameter.

(12) *Solid mandrel stakes.* Solid mandrel stakes are available in lengths of 30, 34 1/2, and 40 inches. Each has the double shank on one end. In general, this stake is used for riveting, forming, and seaming square or rectangular material.

(13) *Hollow mandrel stake.* The hollow mandrel stake has a slot on the lower side in which a large bolt slides, making it possible to fasten the stake securely in any desired position on the bench. This stake comes in overall length of either 40 or 60 inches. It has a square section at one end and a rounded mandrel on the other. This arrangement makes it suitable for riveting, forming, and seaming.

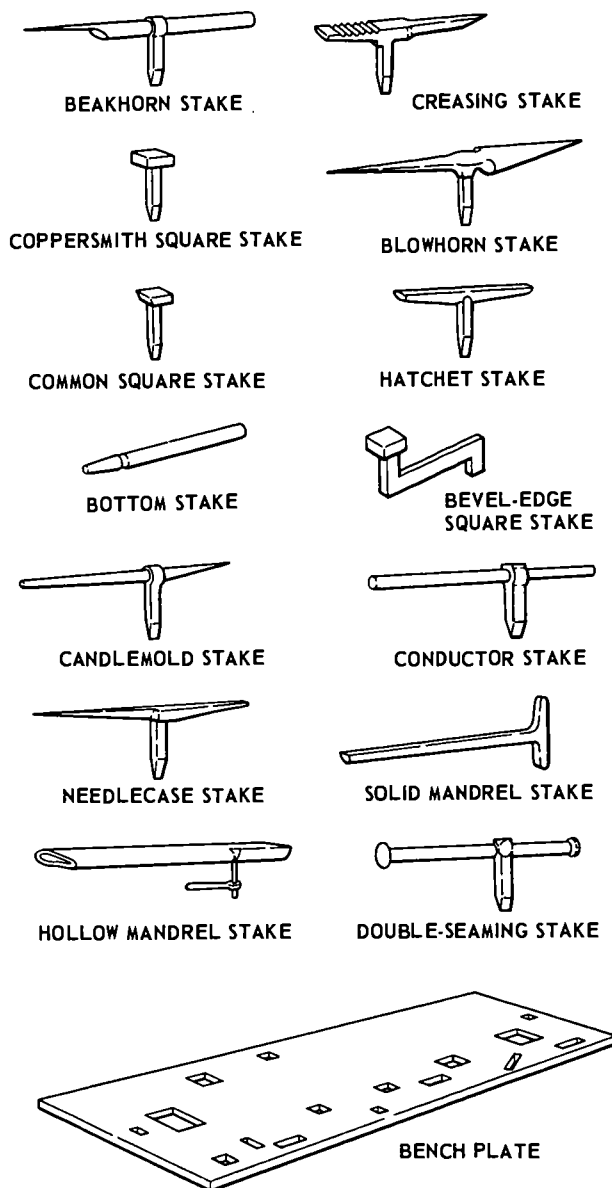


Figure 72. Stakes and benchplate.

38. Metal and Wood Forming Blocks and Sandbags

The forming and processing of metal in various shapes require support, forms, and holding devices for the airframe repairman to perform work efficiently. Metal and wood forming blocks and sandbags are tools that can be used to accomplish this task.

a. V-Blocks. V-blocks made of hardwood are widely used in airframe metalwork for shrinking and stretching metal, particularly angles and flanges. The size of the block depends on the work being done and on personal preference. Although any type of hardwood is suitable, maple and ash are recommended for best results when working with aluminum alloys.

b. Hardwood Form Blocks. Hardwood form blocks can be constructed to duplicate practically any aircraft part, structural or nonstructural. The curved angle strip, as shown in figure 73, has been formed with the use of form blocks. The wooden block or form, as shown in figure 74, is shaped to the exact dimensions and contour of the part to be formed. When shaping the blocks, do the rough work with ordinary wood saws, chisels, gouges, files, and rasps, and perform the final smoothing with sandpaper. Since the form must be accurate, prepare several templates so that the accuracy of the form can be tested at frequent intervals. If the forms are to be used over a period of time, apply several coats of shellac to the blocks to keep them from checking, cracking, or shrinking.

c. Shrinking Blocks. A shrinking block consists of two metal blocks and some device for clamping them together. One block forms the base and the other is cut away to provide space where the crimped material can be hammered. The legs of the upper jaw clamp the material to the base on each side of the crimp so that the material will not creep away, but will remain stationary while the crimp is hammered flat (being shrunk). This type of crimping block is designed to be held in a bench vise. Shrinking blocks can be made to fit any specific need. The basic form and principle remain the same, even though the blocks may vary considerably in size and shape.

d. Sandbags. A sandbag is generally used as a support during the bumping process. A serviceable bag can be made by sewing heavy canvas or soft leather to form a bag of the desired size, and filling it with sand which has been

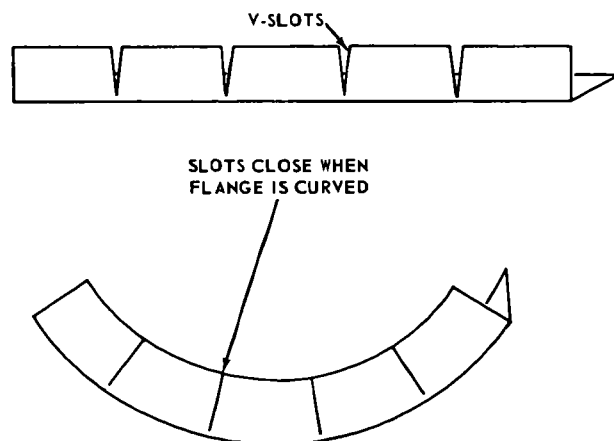


Figure 73. Slots in a curved angle strip.

sifted through a fine mesh screen. Unless a heavy duty sewing machine is available, sew the bag by hand, using a heavy cord. The seam made by an ordinary sewing machine will not be strong enough. Before filling the bag with sand, use a

brush to coat the inside of it with heated paraffin or beeswax, which forms a sealing layer and prevents the sand from working through the pores of the canvas (fig. 75).

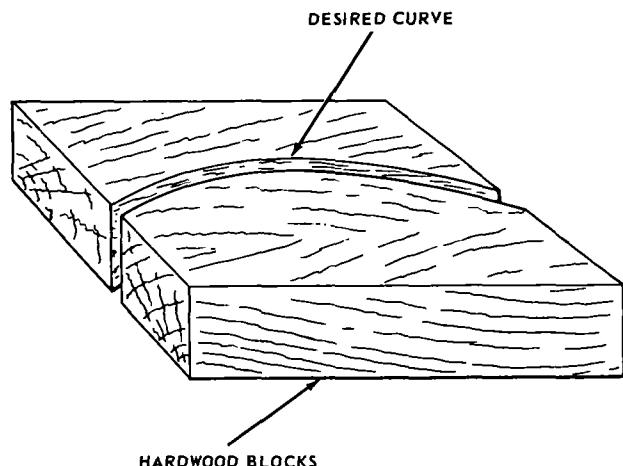


Figure 74. Jig for curving an angle strip.

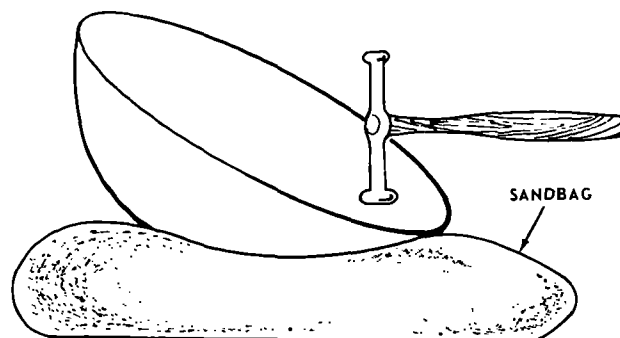


Figure 75. Sandbag.

Section IV. SHEET METAL SHOP EQUIPMENT

39. Metal Cutting Machines (Nonpowered)

The nonpowered metal cutting machines are lever-type, hand-operated equipment designed to assist the airframe repairman in completing heavier and more difficult work.

a. Squaring Shears. Squaring shears provide a convenient means of cutting and squaring metal. These shears, as shown in figure 76, consist of a stationary lower blade attached to a bed and a movable upper or cutting blade attached to a crosshead. A spring is attached to the mechanism of a foot treadle and the cutting blade. The bed has a scale inscribed which features graduations in fractions of an inch. Two squaring fences, consisting of thick strips of metal, attach to the shears. Each fit so that a 90-degree angle is formed with the blades. The squaring fences are used to line and square the metal sheets prior to cutting. To make a cut, the metal sheet is placed on the bed as required. The shear is put in motion by placing the foot on the foot treadle and pressing downward. When pressure is removed, the spring raises the cutting blade and foot treadle. Foot-operated squaring shears will usually cut mild carbon steel up to 22 gage. The capacity is usually indicated on the squaring shears. Three distinctly different operations can be performed with these shears: cutting to a line, squaring, and multiple cutting to specific sizes. The procedures for these operations are—

(1) *Cutting to a line.* Cutting to a line is accomplished by placing the sheet metal on the bed of the shears with the cutting line directly even with the cutting edge of the bed. Hold the sheet securely in place and press down on the foot treadle, bringing the cutting blade down. Apply full pressure to the treadle so that

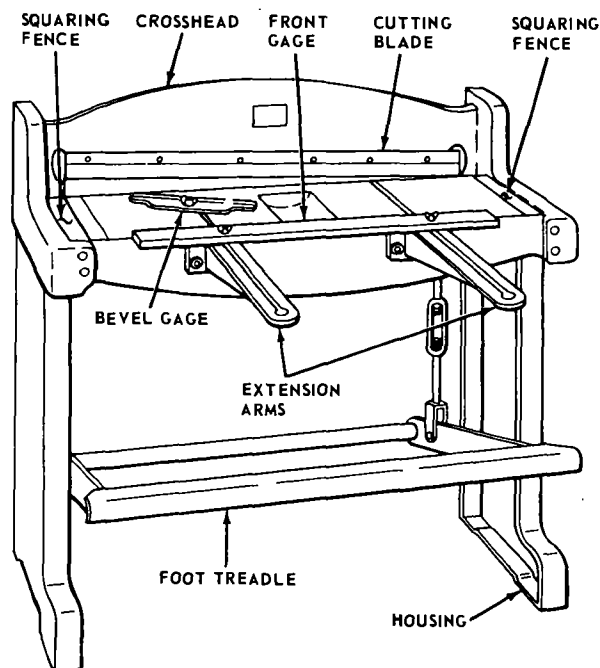


Figure 76. Squaring shears.

the cutting blade will follow and make a complete cutting stroke.

(2) *Squaring*. Squaring requires several steps. First, square one side of the fence with an edge. (The squaring fence is usually used on the edge). Then square the remaining edges by holding one squared end of the sheet against the squaring fence and make the cut, one edge at a time, until all edges have been squared.

(3) *Multiple cutting to specific sizes*. Multiple cutting to specific sizes for several pieces of sheet metal is accomplished by using the front gage on the extension arms of the shears. The extension arms are graduated in fractions of an inch. The front gage can be set at any point on the extension arms. Set the front gage at the desired distance from the cutting blade of the shears. Position each sheet to be cut in full position against the front gage and make the cut. Each sheet can be cut to the same dimensions without measuring and marking each separately.

b. *Slitting Shears*. When long sheets are to be cut lengthwise, they are slit with slitting shears. Shears of this type (known as lever shears) are commonly used in airframe shops. They are usually equipped with a punching attachment on the opposite end for punching holes in heavy sheets. These shears should never be used for cutting bolts or nuts unless there is a special fitting attached for this purpose. Narrow, round materials will break down the cutting edges of the blades.

c. *Scroll Shears*. These shears, as shown in figure 77, are used for cutting irregular lines on the inside of a sheet without cutting through to the edge. The upper cutting blade is stationary while the lower blade is movable. A handle connected to the lower blade operates the machine.

d. *Throatless Shears*. Throatless shears, as shown in figure 78, are best used to cut 10-gage mild carbon sheet metal and 12-gage stainless steel. The shears get their name from their construction; they actually have no throat. There are no obstructions during cutting, as the frame is throatless. A sheet of any length may be cut, and the metal can be turned in any direction to allow for cutting irregular shapes. The cutting blade (top blade) is operated by a hand lever.

e. *Rotary Circle Shears*. The rotary circle shears, sometimes called rotary slitting shears, are used for cutting circles, irregular curves, various cylindrical objects, and slitting metal sheets. The shears consist of frame with a deep throat, bed, adjustable gage yoke, cutter drive gears, rotary cutters, and handcrank. The prin-

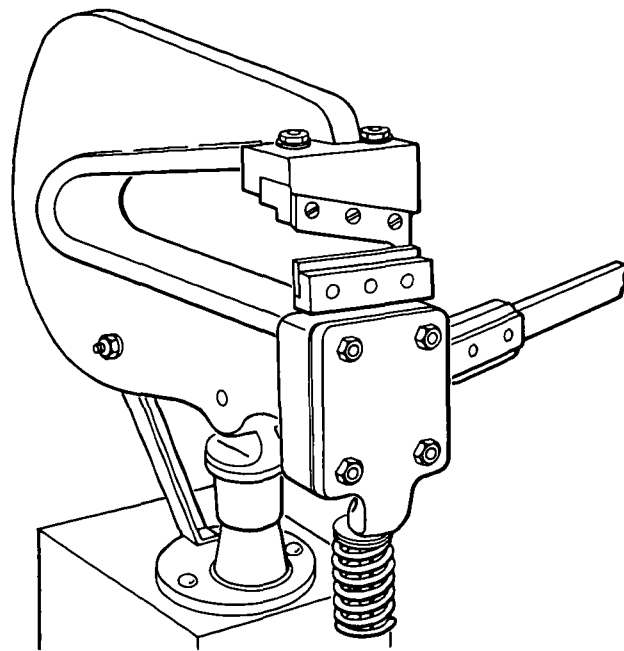


Figure 77. Scroll shears.

cipal parts are the bed, adjustable gage yoke, and rotary cutters.

(1) The bed, since it must absorb and withstand the majority of the load and shock, is made of strong steel plate. On top of the bed is inscribed graduated marks every sixteenth of an inch to indicate the settings as required for various diameters.

(2) The adjustable gage yoke centers and holds the material. The yoke has adjustment features which can be used to position the yoke as required by size of material. The correct position is shown by the graduated marks on the bed. A clamping device attached to the yoke is operated by a clamping handle. The clamping device has disc-type jaws. Setscrews and locknuts are used to adjust the pressure on these clamping discs. There is also a hardened center pin in the lower disc which aids in centering blanks of metal which have been centerpunched.

(3) The rotary cutters can be adjusted in a vertical position and should overlap enough to cut through the metal in one cut. The bottom cutter can be adjusted in a lateral direction. For light gage metal, the cutters should just touch and should operate freely. For cutting heavy material, separate the cutters slightly, but limit the opening to a maximum of 10 percent of the metal thickness.

(4) The cut circular blanks, the first step is to cut the metal to the approximate size. Place this blank in the clamping disc and hold it securely. Adjust the machine so that the

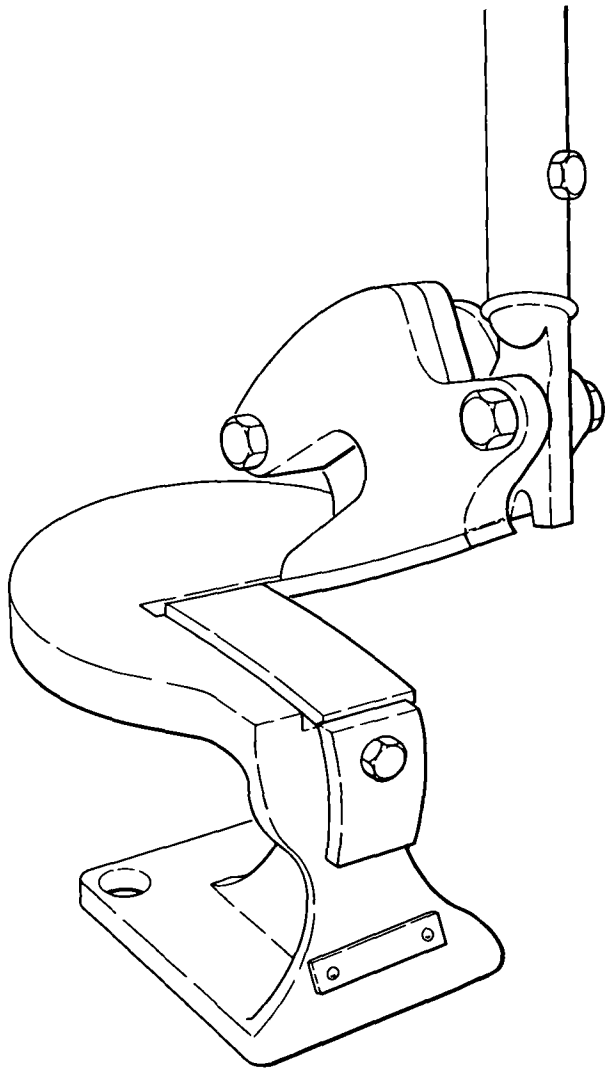


Figure 78. Throatless shears.

distance from the center of the clamping disc to the cutters is one-half the diameter of the blank desired.

(5) The operator should stand at the side of the shears with the cutting head on the right, then the handcrank should be operated so that the work material will feed away from the operator. Always start the cut from the edge of the sheet.

Caution: Never attempt to cut inside circles with these shears.

f. Ring and Circle Shears. The basic construction of the ring and circle shears is similar to that of the rotary circle shears. The difference lies in the cutting head and the upper cutter crank or handle. The cutting heads are set at an angle to each other to permit the cutting of inside circles as well as disc and shallow concave curves. The lateral adjustment between the cutters is the same as for rotary circle shears. Turning the adjustment handle

to the left or right will enable the operator to obtain proper clearance between cutters. For cutting circular blanks with the ring and circle shears, the procedure is the same as for rotary circle shears. To cut a circle out of a circle, or to cut the center out of a sheet of metal, the operation is as follows:

Note. The ring and circle shears are manufactured in a variety of sizes and capacities. Never use the machine to cut material heavier than that for which it is designed.

(1) Adjust the lower cutter for correct clearance and clamp the sheet in the clamping disc. Be sure the distance from the center of the sheet to the cutter wheels is one-half the diameter of the desired blanks.

(2) Set the locknuts on the upper cutter adjustment handle so that the upper cutter is in its lowest position to produce a clean cut.

(3) Turn the handle so that the material is fed away from the operator.

(4) After the cut is made, release the clamping disc and remove the metal.

g. Rotary Punch. The rotary punch, as shown in figure 79, is used to punch holes in metal parts. It can also be used for cutting radii in corners, for making washers, and other jobs where holes are required. This machine is composed of two cylindrical turrets, one mounted over the other and supported by the frame. Both turrets are synchronized so that they operate together, and index pins are arranged so that the turrets are correctly aligned at all times. Particulars of rotary punch operation are—

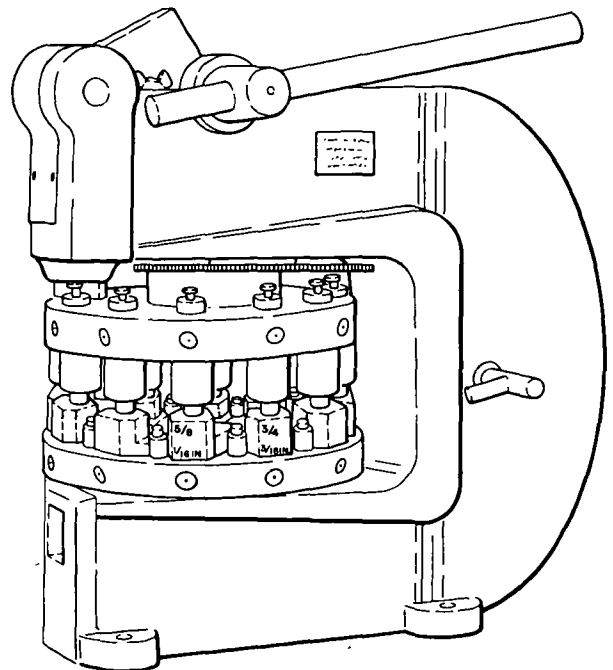


Figure 79. Rotary punch.

(1) To release the index pins from their locked position, rotate the lever which is located at top right side of the punch. This action will withdraw the index pins from the tapered holes and allow the turrets to be turned to any size punch desired.

(2) As the turrets are rotated to change punches, release the index lever when the desired die is within 1 inch of the ram and continue to turn the turrets slowly until the top of the punch holder slides into the grooved end of the ram. The index locking pins will automatically seat in the holes provided, and at the same time, release the mechanical locking device (which prevents punching until the turrets are aligned).

(3) To operate the machine, place the metal to be worked between the die and the punch and pull the lever on the top right side of the machine. This will actuate the pinion shaft, gear segment, toggle link, and the ram, thereby forcing the punch through the metal. When the lever is returned to its original position, the metal is ready to be removed from the punch.

(4) The diameter of the punch is stamped on the front of each die holder. Each punch has a point in its center which is placed in the center punch mark in order to punch the hole in the correct location.

40. Metal Cutting Machines (Powered)

The power-operated metal cutting machines, often called power tools or power equipment, used by the airframe repairman in preparing sheet metal, in some cases are similar to the nonpowered type. Due to the speed or the pressure under which the power tools operate, all safety precautions should be observed to prevent injury to personnel. Airframe repairmen using power tools should be thoroughly familiar with the particular equipment they are to use. The tools most commonly used are—

a. Ketts Saw. The circular-cutting ketts saw, as shown in figure 80, is portable, electrically operated, and uses blades of various diameters. The head of the saw can be turned to any desired angle. It can cut metal up to $3/16$ inch thick; it does not need a starting hole; a cut can be started anywhere on a sheet of metal; and it will cut an inside or outside radius. It is very handy for removing damaged sections on a stringer. To prevent grabbing, keep a firm grip on the saw handle at all times.

Warning: Always check the blade carefully for cracks before installation. A cracked blade can fly apart and perhaps result in injury to personnel.

b. Reciprocating Saw. The reciprocating saw, as shown in figure 81, is portable, airpowered, and has a gun-type shape for balancing and ease of handling. It operates most effectively if the air pressure is from 85 to 100 pounds per square inch. It uses a standard hacksaw-type blade; it can cut a 360-degree circular hole or a square or rectangular hole; and it is easy to handle and safe to use. A reciprocating saw should be used in such a way that at least two teeth of the saw blade are cutting at all times.

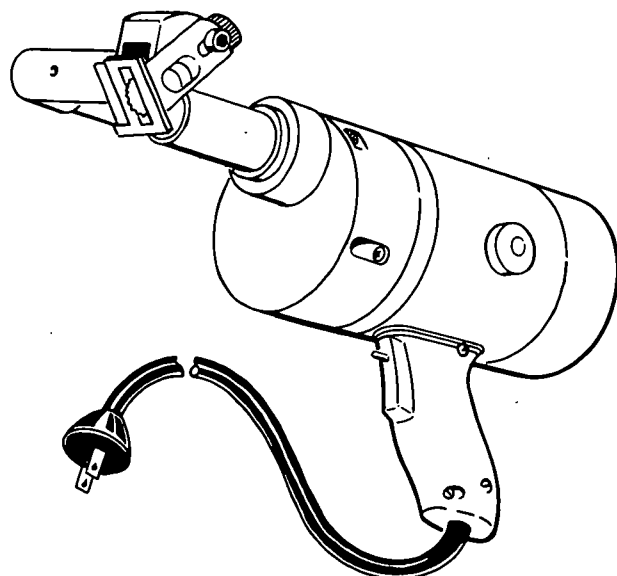


Figure 80. Ketts saw.

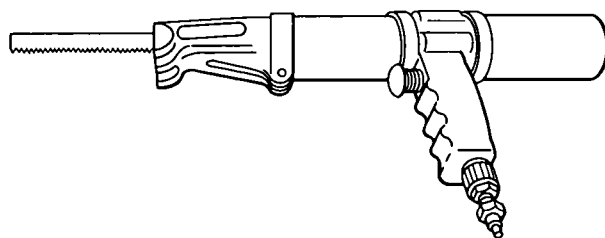


Figure 81. Reciprocating saw.

Caution: Avoid applying too much downward pressure on the saw handle, as this may cause the blade to break.

c. Power Hacksaw. The power hacksaw, as shown in figure 82, has a much greater cutting range than the hand hacksaw; it is used to cut heavier and harder metal. The blade cuts in the same manner as the hand hacksaw. Blades of various types are used; however, high-speed steel, molybdenum steel, or alloy high-speed steel blades are recommended. The operating procedure of the power hacksaw results in several steps of adjustments in its controls as follows.

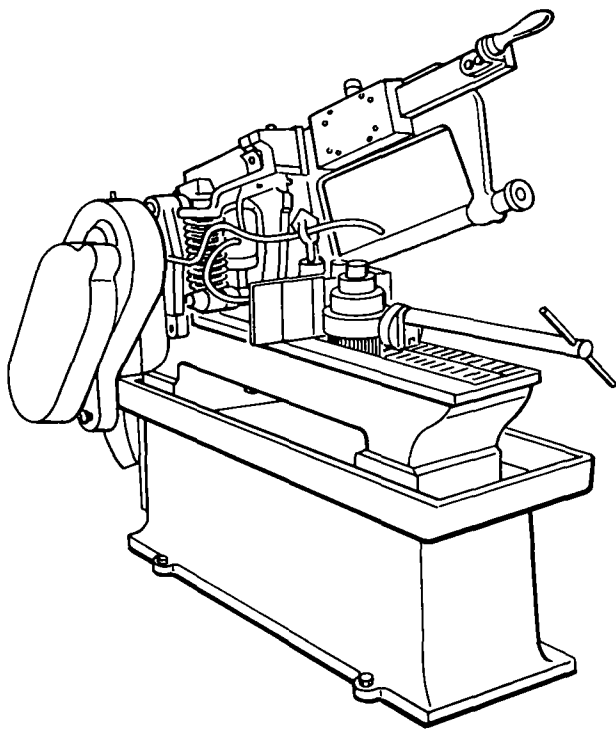


Figure 82. Power hacksaw.

(1) The hydraulic control lever, mounted on the hydraulic unit, has three positions: normal (or neutral), center (or vertical), and feed. When the lever is as far back as possible, it is in the normal or neutral position. Placing the lever in this position permits the saw arm to be moved up and down manually and disengages the clutch. When the lever is in the center or vertical position, the clutch is disengaged and the saw arm is hydraulically locked. The clutch is engaged and the saw arm will reciprocate and feed downward when the control arm is placed in the feed position. A catch or lock is provided to hold the control lever in both the center and feed positions. The catch or lock is engaged by holding the control lever away from the machine, and is disengaged by pressing it toward the machine.

(2) Feed and pressure dials are used to govern the rate at which the saw arm descends and controls the feed automatically. The feeding action is actually affected more by the setting of the pressure dial than it is by the setting of the feed dial. The wider the section of stock to be cut, the greater the pressure dial setting that can be applied, and vice versa.

Note. Always be sure to set the pressure at the point where the blade cuts accurately.

(3) Speeds of approximately 65, 95, and 130 strokes per minute are available through a 3-speed transmission. The high speed is used for cutting nonferrous metals and mild or cold-rolled

steel. The medium speed is used for cutting tool steels and alloys. The low speed is used for cutting high speed steels, high nickel, chrome or manganese steels, and stainless steels.

(4) Setting the saw arm in position to begin cutting can be done either hydraulically or manually. It can be brought down to the work manually by placing the control lever in the normal or neutral position. The hydraulic feed automatically drops the saw arm when the feed control is on and the saw is placed in motion. An automatic knockout and height gage is incorporated in the hydraulic unit to provide an automatic means of disengaging the clutch. The knockout is actuated by the saw guide which encounters an adjustable nut on the threaded knockout rod.

(5) Some power hacksaws have spring-loaded mechanized controls which operate very similar to hydraulic pressure-operated controls.

d. Contour Bandsaw. The contour bandsaw, sometimes called metal cutting bandsaw, as shown in figure 83, is used where the material to be cut is too heavy for cutting with shears or snips; also, where the time required to set up a milling machine or shaper is too great. In such cases, the bandsaw can be used to prepare parts, fittings, or pieces of sheet metal as needed by the airframe repairman. It can also be used to cut a number of similar parts from sheet metal stock.

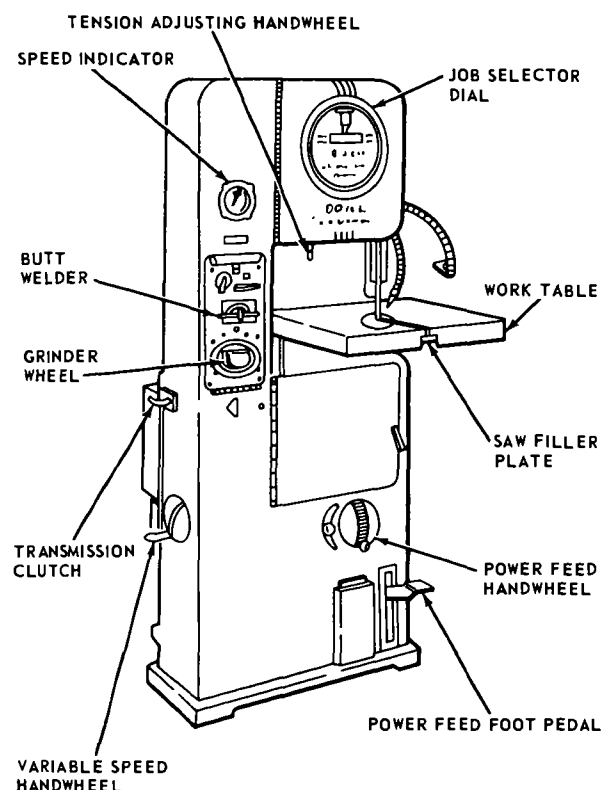


Figure 83. Contour bandsaw.

The particulars of the bandsaw operation are covered in the following steps:

(1) The bandsaw has several speeds, both hand and automatic feeds, and an arrangement by which the table can be adjusted to any angle.

(2) Some saws are equipped with spot welding and grinding attachments which permit the sawblade to be set, inserted, and welded without delay when making internal cuts. This equipment can also be used to mend broken blades.

(3) Continuous file bands and polishing bands are available as accessories for finishing parts once they are cut.

(4) The bandsaw can cut multiple cuts to specific sizes by fastening together pieces of material, either by weld, solder, rivets, or clamps, so that the pieces will hold in place, marking a cut guide line path, and following the line path with the blade.

(5) The changing or installation of the blade is simple; however, there are some definite steps that must be followed. The following procedures are for blade installation. (Changing is practically the same except for reverse order in some cases.)

(a) The blade tension is controlled by a handwheel which has a mechanical arrangement to raise or lower the upper wheel of the bandsaw. The blade carrier wheels (upper and lower) are behind the cover doors, which are just above and below the work table. The cover doors swing out and to the left when facing the front of the bandsaw.

(b) If the blade has to be butt welded, grasp each end of the blade with the hands, making sure the teeth of the blade are pointing downward and toward the operator. Place the ends in the butt welder slots (located above and to left of work table), bring the ends together, and lock in place with the holding screws. Apply current with the arc switch marked for this purpose. The welding process is instantaneous. Loosen the holding screws and remove the blade.

(c) Grasp the right-hand portion of the blade with both hands (about 10 inches apart), making sure the blade teeth are facing toward the operator and pointing downward; then work the blade into the slot on the work table. As the blade proceeds into the slot, tilt the blade by carrying the right hand to the right, and the left hand to the left. This action will allow the blade to pass by the trunnion of the work table. After the blade has passed the trunnion, bring the blade into an upright position and proceed through slot to the blade travel opening of the work table. Hold the blade with the right hand and thread the upper portion of the blade into the telescoping guide leg, onto the contour of the

upper wheel, and finally around the lower wheel.

(d) Making sure the blade is in correct position, bring the tension of the blade in line and recheck the blade to be sure the blade seats properly on the upper and lower wheels and telescoping guide leg.

(e) After proper tension is obtained, the upper wheel must be adjusted (tilted) to provide proper tracking of the blade. Do this by standing to the right of the machine so the blade tracking screw (located on the center of the upper wheel) can be reached with the right hand and the upper wheel with the left hand. This position will allow the wheel to be turned with the left hand. Observe the blade position on the face of the upper wheel, and make adjustment with the blade tracking screw. With the fingers of the left hand placed against the surface of the flat wheel near the rim, rotate the wheel clockwise very slowly and observe the action of the blade. If the blade creeps toward one edge, turn the tracking screw so that it will counteract the creeping tendency of the blade. Repeat this procedure until the blade runs in the center of the upper wheel as the wheel is rotated.

(f) The procedure outlined in preceding steps (a) through (e) should be sufficient; however, it is advisable to make a final adjustment of blade tension and follow up with a recheck of blade tracking. The tracking adjustment is not complete until it is ascertained the blade will stay in place when turning at high speeds. Check this by closing the upper and lower cover doors and pressing the START button to start the motor. After the motor has gained a little speed, press STOP button and see if the blade is tracking near the center of the upper wheel. Do not let the motor accelerate above one-half maximum rpm until it is certain the blade is tracking properly.

(g) After the blade is installed and is tracking properly, make the necessary guide adjustments before using the machine.

e. Power-Operated Squaring Shears. The power-operated squaring shears provide a convenient means of cutting and squaring sheet metal. Remember, this shear is very useful, but it presents a safety problem unless the airframe repairman is completely familiar with its operation and uses it with extreme caution. The power-operated squaring shears, as shown in figure 84, consist of a stationary lower blade, an upper blade attached to a movable crosshead, and a holddown clamp which holds the metal secure. The holddown clamp also allows the operator to get his hands completely out of the way during the cutting operation. The table of the squaring shears has extension arms fastened

to the front edge of the shear bed to provide support for long sheets of metal when they are being cut. On the right side of the machine table surface is a guide (graduated in sixteenths of an inch) that can be used as a measuring scale for short lengths of metal. Also to the right edge of the table surface is an adjustable squaring fence. When properly adjusted, this fence keeps the metal square with the cutting blade. There are two sets of controls used to operate the shear. The switch on the right of the trip levers turns the power on, and the back gage controls cause the back gage to move forward and backward, dependent upon the length of the cut required. There is no need to measure between the back gage and the fixed horizontal blade, as all measurements can be read on the back gage, which is graduated in sixty-fourths of an inch. By pulling the trip levers together at the same time, an automatic clutch is engaged which sets the shearing blade in action. The shear will go through only one cycle of action each time the trip levers are pulled. If continuous operation is desired, simply continue to hold the trip levers together. Once the lever is released, the shears stop at the

completion of the cycle of operation. Operating procedures for the power-operated squaring shears are as follows:

- (1) Check gage of metal to insure that it is within the capacity of the squaring shears.
- (2) Turn on the main power switch.
- (3) Adjust back gage for length to be cut.

This is done by pressing the FORWARD-FAST or BACKWARD-FAST buttons to bring the back gage to approximate position; then use the FORWARD-SLOW button to get the exact setting for the back gage.

- (4) Place the metal on the table of the squaring shears.

- (5) Line up the right edge of the metal so that it is flush with the squaring fence.

- (6) Slide the sheet metal between the top and bottom blades until it reaches the back guide.

- (7) Place one hand on each trip lever and when the motor has reached full speed, press the handles together. The shears will engage and cut the metal. Release the levers and turn the power switch to OFF position.

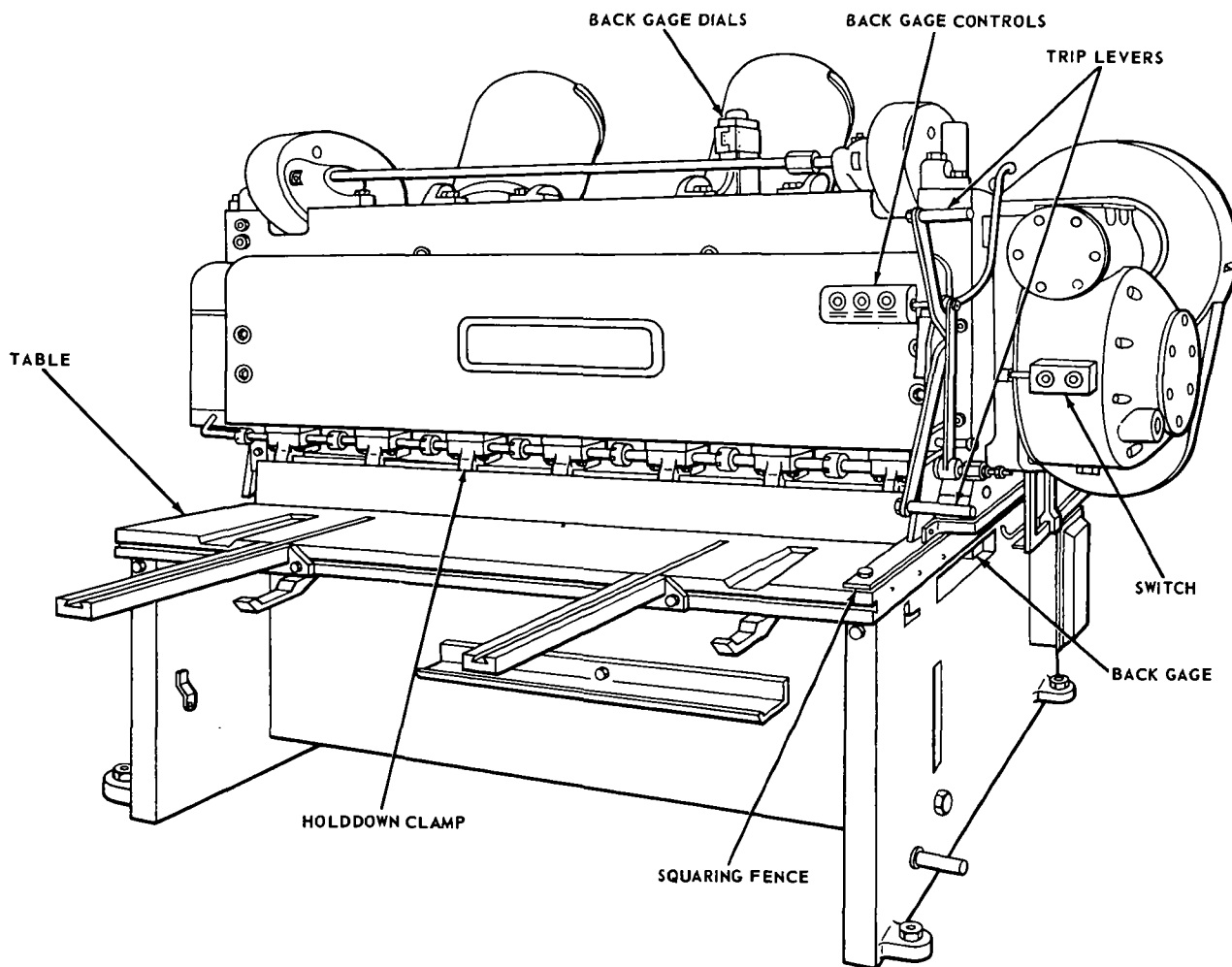


Figure 84. Power-operated squaring shears.

(8) When the moving parts of the squaring shears come to a complete stop, remove the material.

f. Nibblers. Stationary nibblers are used to cut metal by a high-speed blanking or cutting action similar to the operation of the portable nibblers covered in paragraph 35*d*. This action is accomplished by up and down motions of the lower die. The shape of the lower die permits small pieces of the metal, approximately 1/16 inch wide, to be blanked or cut out as the motion of the lower die presses the metal against the surface of the upper stationary die. The cutting speed of the nibblers is controlled by the thickness of the metal being cut. Sheets of metal with a maximum thickness of 1/16 inch can be cut satisfactorily. Too much force applied to the metal during the cutting operation will clog the dies, causing the dies to fail or the motor to overheat. The lower die has a spring-loaded adjustment screw located at the base of the die which controls the movement of the metal. This screw should be adjusted so that the metal will move freely between the dies and, at the same time, be held firmly enough to prevent irregular cuts. The dies can also be shimmed for special cutting.

41. Drills and Drill Presses

Portable power drills and stationary power drill presses are important machine tools used in airframe metalwork. The drilling of holes for rivets and bolts is one of the most common operations performed by the airframe repairman. This operation is not difficult, especially on light metal, if the fundamentals of drills and drill presses and their uses are understood. The small portable power drill is the most practical machine to use, however, there will be times when a stationary power drill press will be the better machine to use. When drilling hard or heavy gage metals, an approved cutting oil should be used during the drilling operation.

a. Portable Power Drills. Some portable power drills are operated by electricity and others by compressed air. Some electrically operated drills will run on both alternating and direct current, while others will operate on only one kind of current. Be sure to check the type current the drill is designed to use before plug connections are made. The portable power drills, as shown in figure 85, are made in various shapes and sizes to satisfy almost any requirement. The chuck of the drill determines the size; that is, the chuck will hold the shank of a twist drill up to the size for which it is designed. The drill

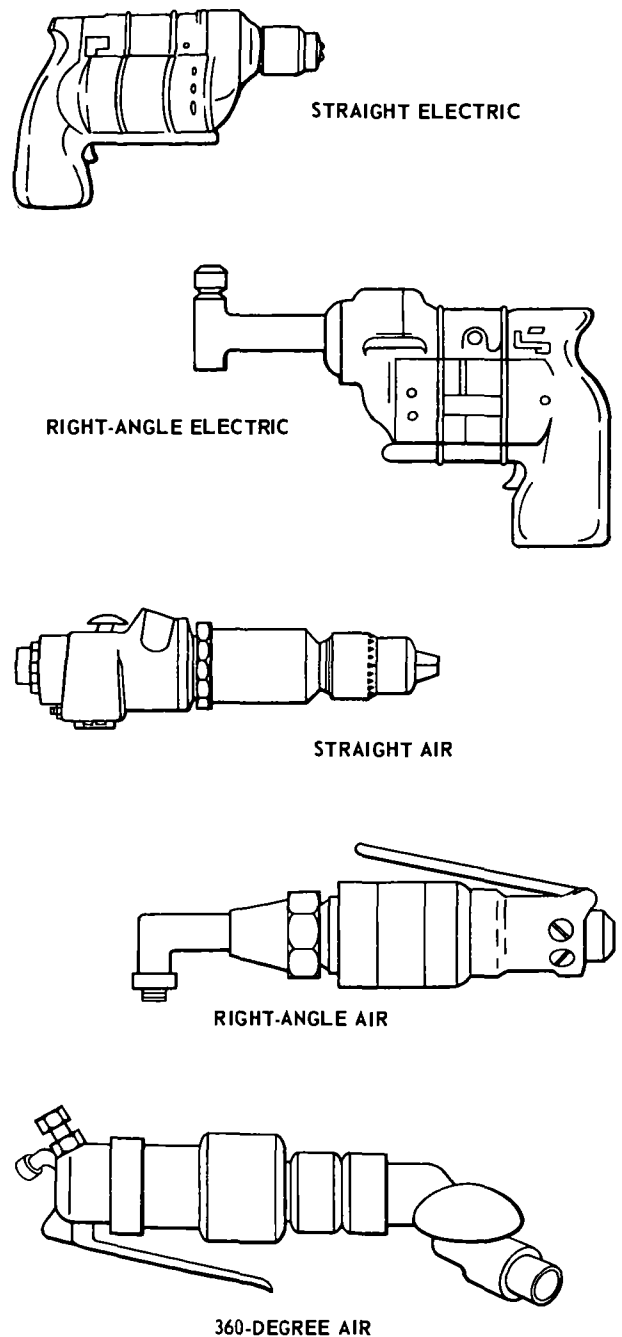


Figure 85. Portable power drills.

used by the airframe repairman generally carries a chuck with maximum capacity of 1/4 inch; however, drills are designed with larger capacity chucks. Pneumatic drills are recommended for use around flammable materials, as sparks from an electric drill are a fire hazard. The twist drill should be inserted in the chuck and tested for trueness. This may be visibly checked by running the motor freely. A drill that wobbles or is slightly bent should not be used, as such a condition will cause enlarged holes. When using a portable power drill, hold it firmly with both hands. Always hold the drill at right angles to

the work, regardless of the position or curvature. Tilting the drill at any time when drilling into or withdrawing from the material may cause elongation (egg shape) of the hole. Some areas of work may be inaccessible to regular drilling. Adapters and extensions can be used to overcome this condition. A straight piece of drill rod can be attached to a twist drill and used as an extension, or a flexible extension can be used to drill around obstructions. Angle adapters can be attached to the chuck. The shank of the adapter fits the chuck; the adapter holds the twist drill. When using an adapter, the drill is held firmly with one hand and the adapter with the other hand.

Warning: Always use safety goggles while drilling, as metal particles can be thrown from the drill with force.

Note. Burrs must be removed from drilled holes so that material can be fitted smoothly and snugly. Burrs can be removed with a bearing scraper, countersink, or a twist drill. If a countersink or twist drill is used, it should be rotated by hand.

b. Stationary Power Drill Presses. The stationary power drill press is a stationary precision machine tool used for drilling holes that require a high degree of accuracy. It serves as an accurate means of locating and maintaining the direction of a hole that is to be drilled, and provides the operator with a drill lever that makes the task of feeding the drill into the work an easy one. A variety of drill presses are available; the most common type is the ordinary upright drill press, as shown in figure 86. The airframe repairman should understand and follow the particulars given in the following steps when using a drill press.

(1) The drill press table can be raised or lowered to accommodate the material or part requiring drilling. The travel of the drill in relation to distance between table location and drill point when drawn out determines if table should be adjusted.

(2) Place the material or part on the table and bring the drill point down and align with hole to be drilled.

(3) The material or part is then clamped to the table to prevent it from slipping during the drilling operation.

Warning: Material or parts not properly clamped could slip and/or bind on the drill and start spinning, causing possible serious injury to the operator and also damage to equipment and/or material or parts. Always make sure the clamps are properly fitted and tightened securely.

(4) There are many different clamping devices which can be used separately or in combi-

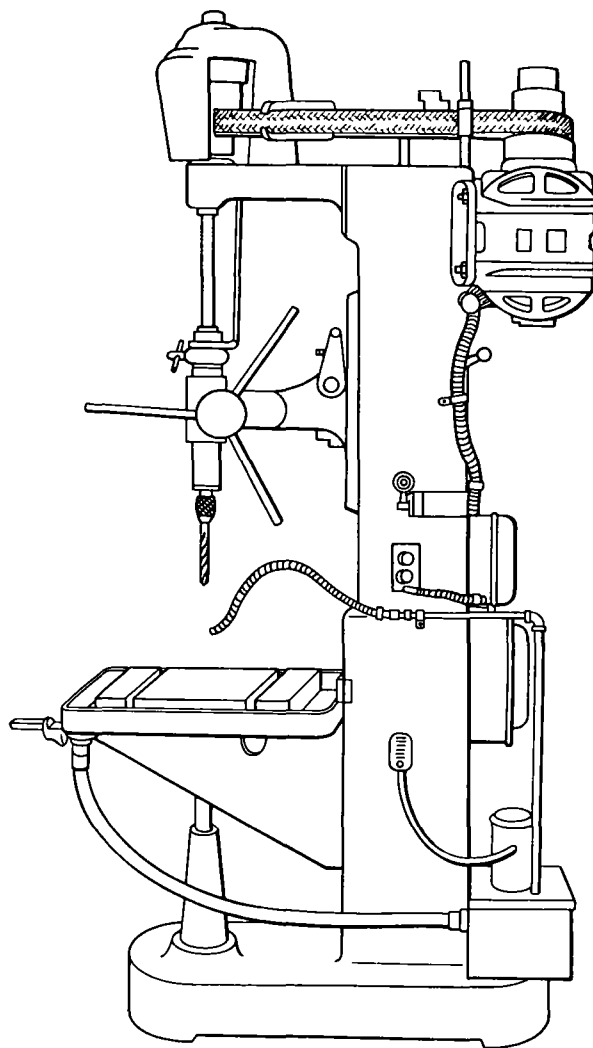


Figure 86. Stationary power drill press.

nation to provide a means of clamping most any job encountered. Experience will enable the airframe repairman to make a quick and accurate selection of clamping devices for a particular job to eliminate time waste in setting up the part in preparation for the drilling operation. Regardless of the clamping device, always place the part on parallels or backup blocks to protect the drill and table from damage.

(5) The drill press should be checked for proper lubrication. Frequent lubrication during continuous operation will help the operating conditions. Keep the oil ports clean and free from foreign particles. Keep the drill press clean and always clean the drill press after each drilling operation.

(6) Belt-driven presses should be checked each day to insure that they are free from grease and dirt. Belt dressing should be applied if belt slippage occurs or if the belt has a tendency to dry out. Belts should be kept at the proper operating tension.

(7) Some drill presses are equipped with gears that provide a means of increasing or decreasing the speed of the spindle. The machine should be stopped when changing gears. If the gears do not mesh, pull on the belt and bring the gears to proper meshing points.

(8) The speed charts should be checked to be sure machine is operated at proper speed and feed for the assigned drilling operation. Continued use of too heavy a feed or too fast a speed will make the machine labor and cause drill breakage or damage to the machine.

(9) The degree of accuracy that is possible to attain when using the drill press will depend to a certain extent on the condition of the spindle hole, sleeves, and drill shank. Therefore, special care must be exercised to keep these parts clean and free from nicks, dents, and warpage. Always be sure that the sleeve is securely pressed into the spindle hole. Never insert a broken drill in a sleeve or spindle. Be careful never to use a vise for clamping a sleeve to remove a drill, as this may cause the sleeve to warp.

42. Grinding-Sanding Machines

The terms grinding and sanding, as applied to the type machines discussed in this paragraph, are mechanical means of removing excess material while producing a suitable surface. There are many kinds of grinding-sanding machines, but only those which are helpful to the airframe repairman are discussed here. The grinding wheels and sanding discs are discussed as they apply to their respective uses.

a. Pedestal Grinder. The pedestal or floor-type grinder usually has a grinding wheel on each end of a shaft which runs through an electric motor or a pulley operated by a belt. This grinder is used for sharpening tools and other general grinding jobs.

b. Wet Grinder. The wet grinder, although similar to the pedestal grinder, differs from it in that it has a pump to supply a flow of water on a single grinding wheel. The water reduces the heat produced by material being ground against the wheel. It also washes away any particles of metal or abrasive removed during the grinding operation. The water returns to an attached tank for reuse.

c. Bench Grinder. A common type bench grinder, as shown in figure 87, is found in most metalworking shops. This grinder may be used to dress chisel points, heads, and screwdriver blade tips, or to sharpen drill points. It may be used for removing excess metal from work and smoothing metal surfaces. This grinder is usually equipped with one medium-grain and one fine-grain abrasive wheel. Over each wheel is a

clear safety shield and also a metal guard shroud. The abrasive wheels are removable, and the grinder is usually designed to use wire brushes, polishing wheels, sanding discs, or buffing brushes. The bearings and motor have cups for lubrication. The grinder operation is simple; however, care should be exercised while using the grinder. The following instructions should always be followed.

(1) Be sure to check the abrasive wheels for cracks or other visible damage before using grinder. Check to be sure the wheels fit tight on the spindles.

Warning: Never operate the grinder without goggles, even if eyeshields are attached to the grinder. Never operate the grinder without wheel guards. Wheel guards serve to protect personnel from injury should slippage of work occur. Anyone who is required to use the bench grinder should be familiar with the hazards involved in its operation. Beware of these hazards and help reduce the accident rate.

(2) Always check wheel guards to be sure they are fitted properly and are tight.

(3) Check to be sure tool rests are aligned and tight.

(4) The metalworker should know the correct angle for cutting tool points or tips before attempting to sharpen them. While sharpening the item, apply feed pressure gradually so that just enough of the surface is contacting the wheel for proper results. Exercise care to prevent feed pressure from causing excessive heat while sharpening.

(5) As a rule, it is not a good practice to grind work on the side of an abrasive wheel. When an abrasive wheel becomes worn, its cutting efficiency is decreased because surface speed is affected. When a wheel becomes worn in this manner, it should be replaced.

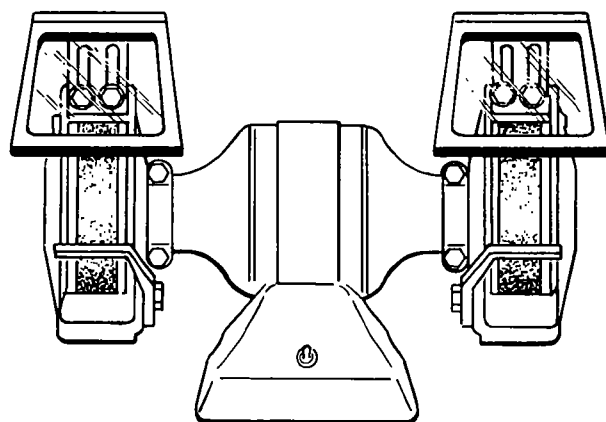


Figure 87. Bench grinder.

(6) The grinding operations usually require the use of both abrasive wheels. First, the medium or coarse wheel is used when removing rough surfaces, when a considerable amount of material is to be removed, or when a smooth finish is unimportant. The finer wheel is used for sharpening tools and grinding to close limits. This wheel removes the metal slower and gives a smoother finish.

43. Metal Forming Machines

In aircraft metalwork, the expression *forming metal* usually means shaping or bending metal in two dimensions. This operation is more difficult than bending in one dimension, as some portions of the metal must be stretched or shrunk. Some phases of metal forming work are accomplished with hand tools; however, many airframe repairs have to be accomplished by use of powered and nonpowered machine tools, such as metal cutting machines, grinders, and others, along with metal forming machines. The metal forming machines discussed may be either hand-operated or power-driven. Small machines are usually hand-operated, while the larger ones are power-driven.

a. Bar Folder. The bar folder, or bar folding machine, as shown in figure 88, is a type of folding machine designed to make turns (or bendovers) and narrow edges; to fold small hems, flanges, and seams; and to turn rounded locks on flat sheets of metal to receive stiffening wires. Most bar folders have a capacity for forming metal up to 22 gage in thickness and 42 inches in length. The airframe repairman should understand the operation and be thoroughly familiar with the adjustment procedure to set up the bar folder before any attempt is made to operate the machine. Several adjustments must be made, including adjustments for metal thickness, width of fold, sharpness of fold, and angle of fold. These particulars are as follows:

(1) *Thickness of material.* The adjustment for the thickness of material is made by adjusting the screws at each end of the bar folder. As this adjustment is made, place a piece of metal of the desired thickness in the bar folder and raise the operating handle until the small roller rests on the cam. Hold the folding blade in this position, and adjust the setscrews so that the metal is clamped securely and evenly the full length of the folding blade. After the folder has been adjusted, test each end of the machine separately with a small piece of metal by actually folding it.

Caution: Be extremely careful to avoid adjusting the bar folder too tight. If the adjustment

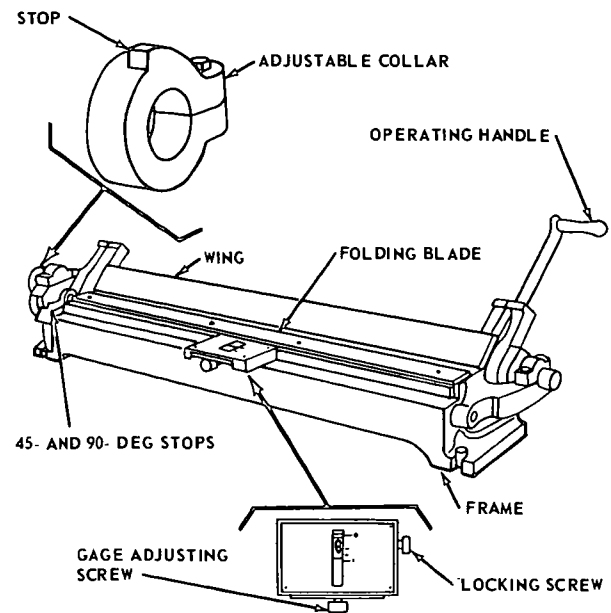


Figure 88. Bar folder.

is too great, the clamping pressure can cause damage to the clamping blade. The machine is designed to operate freely; if it does not operate freely, the adjustment is too tight.

(2) *Width of fold.* The width of the fold is controlled by the gage adjusting screw located near the center of the bar folder frame, just under the folding blade. This screw moves the slide and gage back and forth as necessary for the width of the desired fold. The gage is graduated in fractions of an inch from 0 to 1 inch, as a 1-inch fold is the largest that can be made on the bar folder. (Larger folds are made by use of the cornice brake.) After the adjustment is made, lock the gage in place by tightening the locking screw, located on the right side of the gage.

(3) *Sharpness of fold.* The bar folder can be used for making either sharp or round folds. The sharpness of the fold is controlled by raising or lowering the wing. The wing is supported by a wedge which has adjusting features. The wedge adjusting knob is located in the center of the folding blade. Before wedge adjustments can be made, the wing must be perpendicular to the folding blade. To make a sharp fold, set the wedge so the wing will stay in the same position throughout a cycle of operation. To make a round fold, adjust the wedge so that the wing will be forced back as the fold is made.

(4) *Angle of fold.* There are two positive stops on the bar folder, one for 45-degree folds or bends and one for 90-degree folds or bends. An additional feature (an adjustable collar) is provided and can be adjusted to any degree of

bend within the capacity of the bar folder. To form angles of 45° or 90°, the stop for angle desired is moved into place and set. The operating handle will move forward to the stop, thus forming the desired angle. For forming of other angles, the adjustable collar is used. This is accomplished by loosening the setscrew and setting the stop at the desired angle. After setting the stop, tighten the setscrew and form the bend.

(5) *Making the fold.* After adjusting the bar folder for the desired fold, insert the metal between the folding blade and the jaw. Hold the metal firmly in place against the gage. As the operating handle is pulled forward, the jaw automatically raises and holds the metal until the desired fold is made. When the operating handle is returned to its original position, the jaw and blade also return to their original positions and the metal will be released.

b. Cornice Brake. The cornice brake, as shown in figure 89, is more versatile than the bar folder. It is used to form locks and seams; turn edges; and make squares, angles, and bends. It operates similar to a bar folder except that a clamping bar takes the place of the stationary jaw used on a bar folder. Any bend formed on a bar folder can also be made on the cornice brake. In comparison, the cornice brake allows the sheet (that is to be folded or formed) to pass through the jaws from front to rear without obstruction. The bending capacity of a cornice brake is determined by the manufacturer. Standard capacities of this machine are from 22- to 12-gage sheet metal and bending lengths are from 3 to 12 feet. The bending capacity of the brake is determined by the bending edge thickness of the various bending leaf bars. Like the bar folder, several particulars are given to aid the airframe repairman to properly operate the cornice brake.

Caution: Never use the cornice brake to bend wire, rods, band iron, or spring tempered metal sheets. The working surfaces of the cornice brake could be damaged due to the material composition and shapes of these items.

(1) In making ordinary bends with the cornice brake, the sheet is placed on the bed with sight line (mark indicating line of bend) directly under the edge of the clamping bar. The clamping bar is then brought down to hold the sheet firmly in place. The stop at the right side of the cornice brake is set for the proper angle or amount of bend, and the bending leaf is raised until it strikes the stop. If other bends are to be made, the clamping bar is lifted and the sheet is moved to the correct position for the bend.

(2) When bending sheets heavier than 22 gage, the clamping bar should be raised an amount equal to the thickness of the metal and set back the same distance. When bending sheets heavier than 22 gage, reinforce the bending leaf with angle iron.

(3) To get the most out of the cornice brake, the airframe repairman should know how to adjust it for various operations. These adjustments are very important because they save time and improve the quality of the work.

(a) The cornice brake must be level on the floor to prevent the top leaf from creeping when clamping metal between jaws. Should the top leaf creep, adjust slot casting adjustment screws and slot casting lock screws (fig. 89). Also, a wedge can be placed under the rear legs on the side that creeps. The wedge should be fashioned for permanent setting.

(b) Check the bending leaf when it is in the down position. The edge of the leaf should be 1/64 inch below the bed edge at the ends and 1/32 inch below bed edge at the center. To obtain and maintain this alignment, use the following steps:

1. Adjust leaf ends with bending leaf hinge adjustment screws (fig. 89).
2. Adjust leaf center with bending leaf adjustment bolt.
3. Adjust bend ends with bed end adjustment screws and bed adjustment bolt.

(c) In bending various thicknesses of sheet metal with the cornice brake, the top nose bar (fig. 89) should be moved back at the bending edge. If the material to be bent is within 4 gages of the capacity of the cornice brake, the top leaf should be moved back in distance equal to twice the thickness of the material to be bent. To perform sharp bends on lightweight material, move the top leaf forward. The particulars that should be followed in relocating the top leaf to make these bends are—

1. Loosen the slot casting lock screws (fig. 89).
2. Reposition the top leaf forward or backward as required by metal thickness. This is accomplished by using the slot casting adjusting screws. (These screws have right-hand threads.)
3. When the top leaf is adjusted to desired position for bending, lock the leaf by tightening slot casting lock screws firmly.

(d) The clamping pressure should be firm enough to hold the metal in place while the bend is being made. Different gages of metal will require different adjustments. Remember that every gage of metal will have its own adjustment

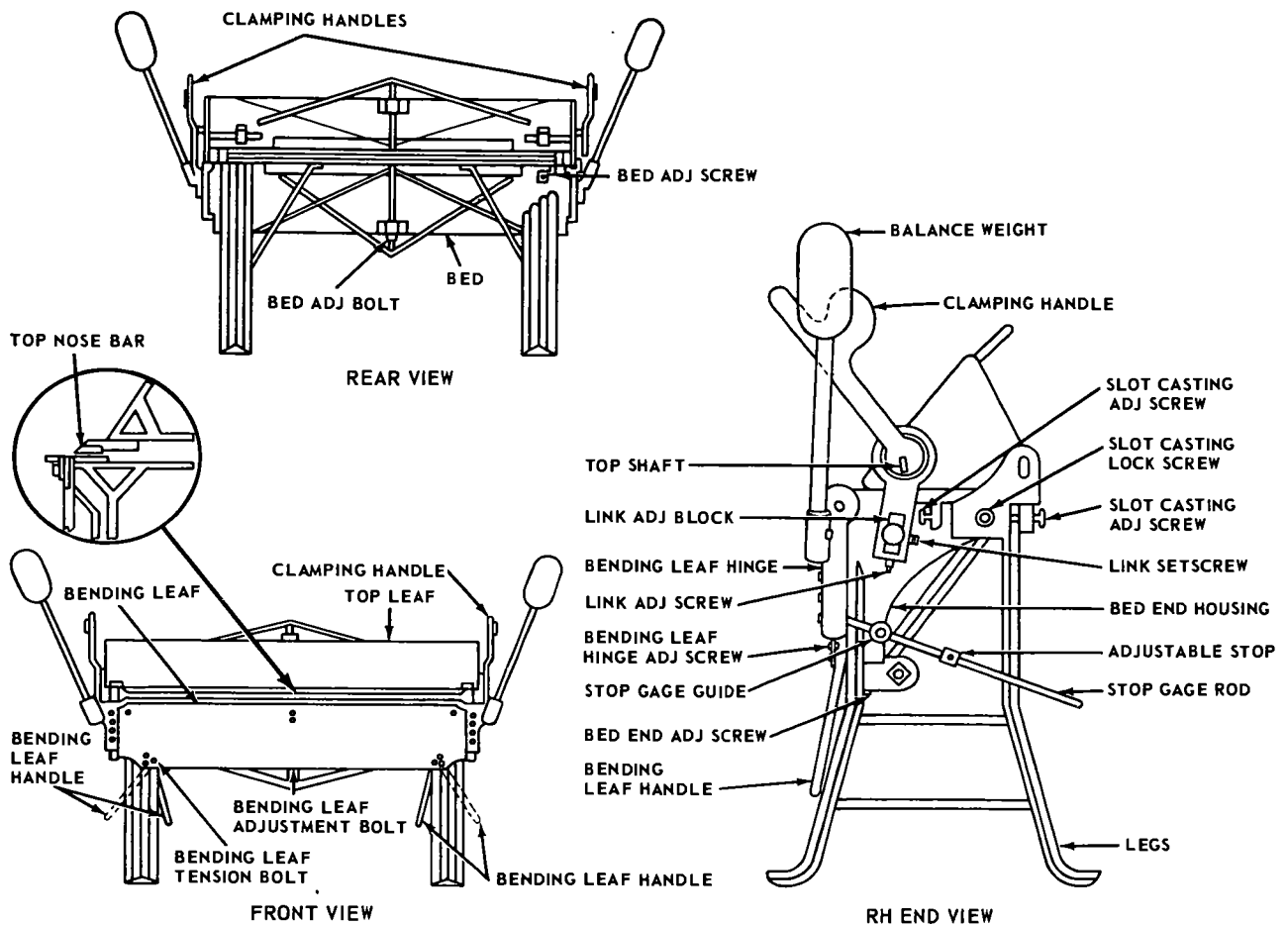


Figure 89. Cornice brake.

and that the clamping pressure should be equal on both ends of the machine. This clamping pressure can be changed by adjusting the link adjusting block (fig. 89) as follows:

1. Loosen link setscrews.
2. Adjust line adjusting blocks to thickness of metal with line adjusting screws.
3. Secure the link adjusting blocks in place by tightening link setscrews.
4. Use a test strip of metal and make a bend to be sure the adjustments are correct. Repeat the procedures if necessary to get correct adjustments.

(e) Most metals have a characteristic known as *springback*, which means they have a tendency to return to their normal shape. If the cornice brake is set for a 90-degree bend, the metal bend will probably form an angle of about 87° to 88°; therefore, if a bend of 90° is desired, the cornice brake should be set to bend an angle of about 93° to allow for springback. There will also be occasions when the material will bend excessively or will bend further on one side of

the brake than on the other. To correct this condition, set the top leaf back on the end where the sheet is overbending. If the bending leaf becomes bowed after repeated heavy use, tighten both bending leaf tension bolts until the center is brought into line. This line should be a straight line; check it with a straightedge.

(4) Molds or formers can be obtained in half-round sizes such as 5/8, 1, 1 5/8, 2 1/4, and 3 inches. They are used most often to make gutters. These formers are attached to the cornice brake by means of clamps. When attaching the formers to the brake, there should be 1/2-inch clearance on the side of the formers against the bending leaf. Position the clamps vertically to the ground, and tap lightly with a mallet. This creates enough friction to hold the formers in place. When the need arises to remove the clamps, tap upward with a mallet.

c. *Box and Pan Brake.* The construction of the box and pan brake is similar to that of the cornice brake except that the clamping leaf is divided into sections called fingers or shoes. These fingers vary in width and are all interchangeable.

This machine is especially designed for making boxes of various sizes and shapes, as it permits the forming of all sides without distorting any of the finished bends. If the need arises, this machine can be used to do any work that can be accomplished on a standard cornice brake. The adjustments (such as radius and thickness) can be accomplished by the same procedures given for the cornice brake. The fingers must be securely seated and the thumbscrews tightened before using the brake. To remove any of the fingers, simply loosen the thumbscrews, raise the clamping fingers by pushing the clamping bar backward, and then pull the fingers forward. When installing the fingers, reverse this procedure. Before performing any work with the box and pan brake, be sure all adjustments are made for the gage of metal to be used.

Caution: The box and pan brake should never be used to bend wire, rods, band iron, or spring-tempered metal sheets. The working surfaces of the brake could be damaged due to material composition and shapes of these items.

d. Slip-Roll Former. The slip-roll former, as shown in figure 90, is used to form sheet metal into various cylindrical shapes and diameters. It consists of right- and left-hand end frames, gear box, three solid steel rolls, hand crank, and bed. Two of the steel rolls, called front rolls, serve as feeding or gripping rolls. These rolls are turned by a system of gears inclosed in the gear box. The gear system is operated by the handcrank. The rear roll serves as an idler, which shapes the metal to the proper curvature as the geared rolls turn. The front rolls are adjusted by means of two front adjusting screws located at each end of the machine. The rear roll is adjusted by means of two screws located at the rear of each end frame. The front and rear rolls are grooved to permit forming of objects with wired edges. The upper roll is equipped with a release which permits easy removal of the metal after it has been formed. The airframe repairman should follow closely the procedures given in the following steps when using the slip-roll former.

Warning: Before the slip-roll former is turned, be sure that fingers or loose clothing are clear of the rolls before the actual operation is started.

(1) The proper adjustments must be made to the rolls before using the slip-roll former.

Caution: If the object has a folded edge, there must be enough clearance between the rolls to prevent damaging or flattening the fold. The rolls must be clean and free of imperfections.

(2) The lower front roll must be raised or lowered so the sheet of metal can be inserted. Knurled thumbscrews at each end of the machine provide means to adjust this roll. The rear roll must be adjusted to give proper curvature to the part being formed. The adjusting screws provided for this are located at the rear of each end frame.

Note. There are no gages that indicate settings for a specific diameter; therefore, trial-and-error settings must be used to obtain the desired curvature.

(3) The metal should be inserted between the rolls from the front of the machine. Start the metal between the rolls by rotating the operating handle in a clockwise direction.

(4) A starting edge is formed by holding the operating handle firmly with the right hand and raising the metal with the left hand. The bend of the starting edge is determined by the diameter of the part being formed. If the edge of the part is to be flat or nearly flat, a starting edge should not be formed. Rotate the operating handle until the metal is partly through the rolls, and change the left hand from the front edge of the sheet to the upper edge of the sheet. Then roll the remainder of the sheet through the machine.

(5) If the desired curvature is not obtained, return the metal to its starting position by rotating the handle counterclockwise. Raise or lower the rear roll, and roll the metal through the rolls again. Repeat procedure until the desired curvature is obtained, then release the upper roll and remove the metal.

(6) If the part to be formed has a tapered shape, the rear roll should be set so that the rolls on one end are closer together than on the opposite end. The amount of this adjustment will have to be determined by experiment.

(7) If the job being formed has a wired edge, the distance between the upper and lower rolls and the distance between the lower front roll and the rear roll should be slightly greater at the wired end than at the opposite end.

e. Power-Operated Forming Rolls. Another type of forming rolls are those which are power-driven by an electric motor. Usually this type of roll is stronger in construction than the manually operated type. Extreme caution should be exercised at all times when operating these rolls. The methods and procedures for operation used in forming metals are basically the same for both types of rolls.

f. Power-Operated Flanging Machine. The power-operated flanging machine, as shown in figure 91, is designed for forming many kinds

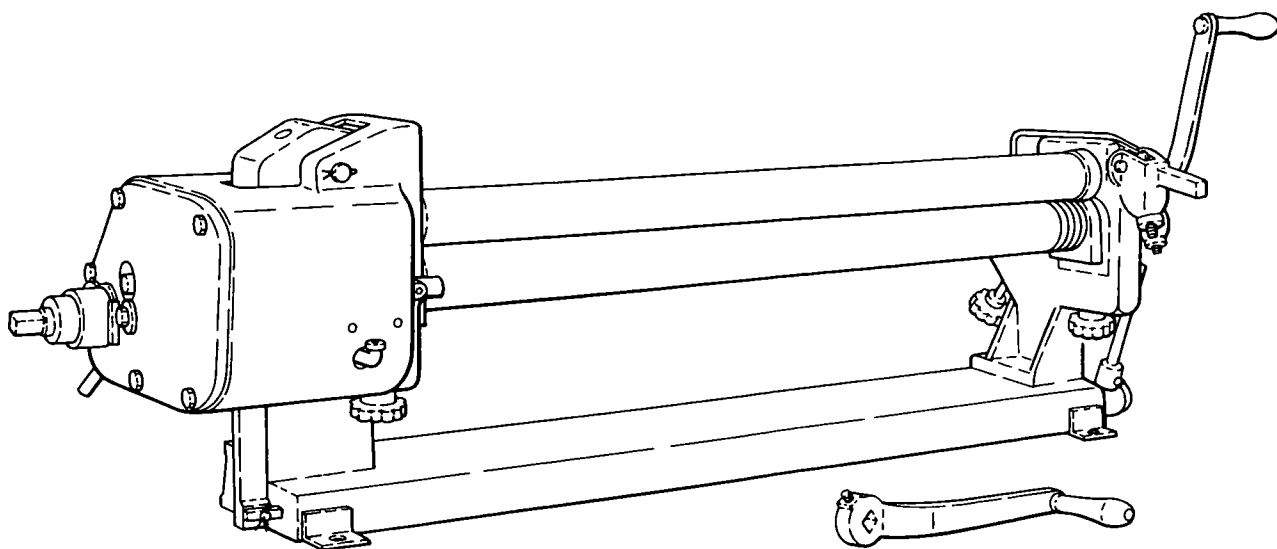


Figure 90. Slip-roll former.

of flanges and hems from flat or irregular sheet metal. Sheet metal up to 10 gage mild steel can be formed on this machine. Special dies, each designed for a special radius or shape, are used with this machine. The procedures involved in the use of this machine are as follows:

- (1) Determine the size, type of flange, and the gage of repair material.
- (2) Select the correct holddown tool, brake tool, and spacers for the flange to be formed.
- (3) Raise the brake head by pushing the trip lever handle backward.

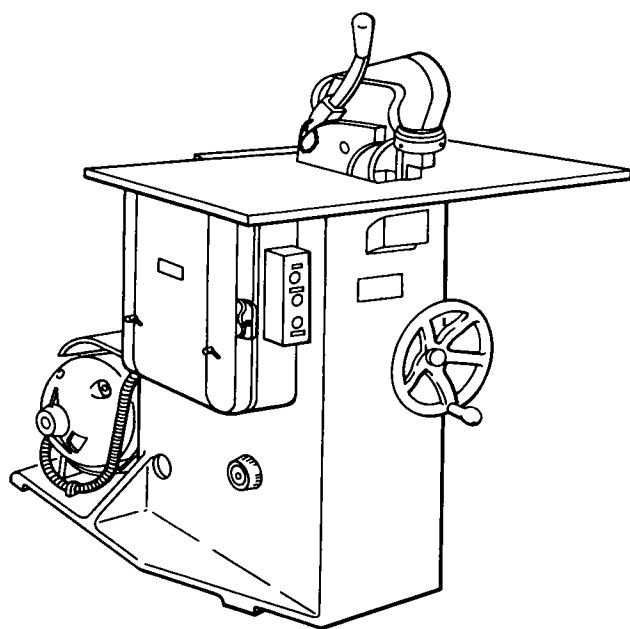


Figure 91. Power-operated flanging machine.

- (4) Install the spacer, brake tool, and hold-down tool.

- (5) Lower the brake head by pulling the trip lever handle forward.

- (6) Turn the flywheel by hand and place the brake head in the lowest position.

- (7) Place the metal to be flange-formed between holddown tool and table. Make adjustments to the holddown tool with the vertical adjustments.

- (8) Remove the metal and turn the hand-wheel so that the brake tool will be in the vertical position.

- (9) Adjust the clearance for the flanges by using the horizontal adjustments.

- (10) Turn the flywheel by hand to determine if the flange-forming parts move freely.

- (11) Turn the handwheel and lower the brake tool to its lowest position.

- (12) Raise the brake head and insert the metal sheet under the holddown tool. The edge of the metal should touch the finger guide.

Note. Oil may be used to lubricate the metal for ease in movement.

- (13) Lower the brake head into position. Revolve the flywheel by hand to check machine movement.

- (14) Start the machine at a slow speed and turn the handwheel until brake tool bends the flange-approximately 30°.

Warning: Keep the fingers away from the hold-down and brake tool while the machine is in operation.

- (15) Slowly move the metal back and forth under the holddown tool. Keep the contoured

edge against the finger guide until the entire flange starts forming.

(16) Raise the brake tool with the hand-wheel at intervals. Frequently check the brake tool screws. (They have a tendency to loosen.)

Note. The one operation can be speeded up after the

flange is bent approximately 60°, if desired, by stopping the machine and changing to a higher speed.

(17) After the flange is formed, lower the brake tool to the lowest position and stop the machine. Raise the brake head and remove the work.

CHAPTER 5

ENGINEERING DRAWING AND BLUEPRINT READING

Section I. INTRODUCTION

44. General

Industry does not depend entirely upon written or spoken words for the exchange of ideas because misunderstanding and misinterpretation may result when these methods are used alone. Engineering drawing is the descriptive graphical language used by engineers and draftsmen to express information required for the fabrication or assembly of objects. This graphical language provides precise information of every detail needed to make a part or assembly. Engineering drawings are reproduced as blueprints. A single view or a system of related views (fig. 92) makes it possible to interpret the shape of an object and visualize it; this interpretation process is known as blueprint reading. In order to interpret blueprints, it is very important that the airframe repairman understand the meaning of the different lines, notes, abbreviations, and symbols used.

45. Descriptive Terms

To convey an accurate description of an object by using a drawing, the person describing the object and the one for whom the description is made must use a uniform definition of the terms. The following explanations are given to help understand the terms in this chapter.

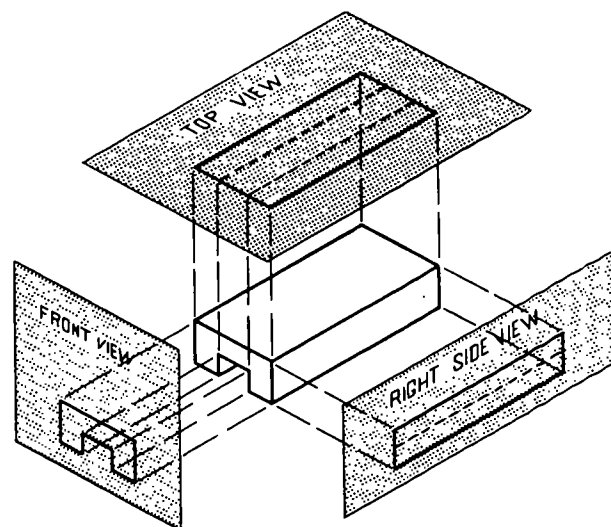
a. Length. This term usually refers to the greatest dimension of an object or the greatest dimension of any part of the object being described. For example, figure 93 shows a board to which a cleat has been attached. We speak of the board as being 24 inches in length and, at the same time, of the cleat as being 18 inches in length. In both cases, the length is the greatest dimension of the object.

b. Width. This term usually refers to the dimension of an object from side to side or in a direction at right angles to the length. In figure 93, the board is 18 inches in width and the cleat is but 3 inches in width.

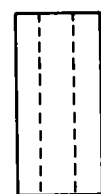
c. Thickness. This term usually refers to the smallest dimension of the object or the smallest dimension of any part of the object being described. It must be remembered in using this term that it can apply either to the main part of the object or to some separate part attached to the object being described. It can also apply to a part projecting from the object; however, it does not apply to a groove cut in an object. Figure 93 shows that the board is $\frac{3}{4}$ inch in thickness and that the cleat is 1 inch in thickness.

d. Height. This term is used to indicate a dimension of an object, or a part of it, which rises above either the surface of the object being described or the one upon which it stands. For example, if a block is placed upon a table in a position so that its greatest dimension is upright (standing on end), instead of referring to this dimension as length, the dimension would be referred to as the height of the block. In figure 93, the block is 3 inches high; that is, the top is 3 inches above the bottom or above the surface on which it stands.

e. Depth. Depth is a perpendicular measurement downward from the top surface or backward from the front. Note in figure 93 the drawing of a block with a groove in the top surface. This groove is $\frac{1}{2}$ inch in depth, meaning that it extends $\frac{1}{2}$ inch below the top surface of the block.



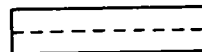
PLANES OF VIEW



TOP VIEW



FRONT VIEW



RIGHT SIDE VIEW

DRAWING ARRANGEMENT OF VIEWS

NOTE:
THE MOST CHARACTERISTIC SHAPE OF
AN OBJECT IS VIEWED FROM THE FRONT.

Figure 92. Relationship of views.

Section II. TYPES OF LINES AND SCALE AND SIZE

46. Types of Lines

Being able to read this printed page depends upon skill in recognizing the characters of the alphabet. In addition to recognizing these characters, a person must know how they are used in the construction of words and sentences. Likewise, being able to read drawings and blueprints depends upon a person's ability to recognize the character of the lines used in the making of drawings, and to understand how they fit into the description of objects as represented. Because of their fundamental importance, these lines are called the *alphabet of lines*.

a. Centerlines. For the sake of accuracy in the construction of many objects it is essential to lay off the dimensions from the center of the object rather than from a face or a side. This is particularly true of circular objects or objects made up of circular curved parts. The line used to indicate the central axis of an object is known

as a centerline. Centerlines are composed of long and short dashes, alternately and evenly spaced with a long dash at each end, and at intersections the short dashes intersect. Very short centerlines (fig. 94) may be broken if there is no confusion with other lines. Centerlines also are used to indicate the travel of a center.

b. Dimension Lines. If a drawing is to be satisfactory, it must indicate not only the correct shape but the size of the object and all of its features. The dimensions and various features are indicated by lines known as dimension lines (fig. 94). Dimension lines will terminate in arrowheads at each end. They will be unbroken on construction drawings and will be broken on production drawings only where space is required for the dimension.

c. Leader Lines. Leader lines (fig. 95) are used to indicate a part or portion to which a number, note, or other reference applies and will

terminate in an arrowhead or a dot. Arrowheads should always terminate at a line; dots should be within the outline of an object. Leaders should terminate at any suitable portion of the note, reference, or dimension. Penetration of leaders is permissible when necessary for clarity.

d. Break Lines. Short breaks will be indicated by solid, freehand lines (fig. 95). For long breaks, full, ruled lines with freehand zigzags will be used (fig. 95). Shafts, rods, and tubes that have a portion of their lengths broken out will have the ends of the break drawn as shown in figure 94.

e. Phantom Lines. Phantom lines (fig. 94) will be used to indicate the alternate position of delineated parts of the item, repeated detail, or the relative position of an absent part. They will be composed of alternating one long and two short dashes evenly spaced with a long dash at each end.

f. Sectioning Lines. Sectioning lines (fig. 94) will be used to indicate the exposed surfaces of an object in a sectional view. They are generally full thin lines but may vary with the kind of material shown.

g. Extension Lines. Usually, the draftsman tries to place all dimensions of an object outside of its outline. This is done primarily for neatness and clarity. However, this is not always possible, as many objects have features on more than one surface, making it necessary to place dimensions within the outline. Whether dimensions are placed within or outside the outline of the surface, the limits of the dimensions must be extended out and away from the feature whose dimension is being shown, otherwise the dimension lines will become confusing. Lines used to extend the limits of a dimension out and away from the feature itself are called extension lines (fig. 94). Extension lines will not touch the outline.

h. Hidden Lines. Hidden lines (fig. 94) will consist of short dashes evenly spaced and will be used to show the hidden features of a part. They will always begin with a dash in contact with the line from which they start, except when such a dash would form a continuation of a full line. Dashes will touch at corners and arcs will start with dashes at the tangent points.

i. Stitch Lines. Stitch lines (fig. 95) will be used to indicate the stitching or sewing lines on an article. They will consist of a series of very short dashes, approximately half the length of the dash of hidden lines, evenly spaced. Long lines of stitching may be indicated by a series of stitch lines connected by phantom lines.

j. Outlines or Visible Lines. The outline, or visible line (fig. 94), will be used for all lines in the

drawing representing visible lines on the object.

k. Datum Lines. Datum lines (fig. 95) will be used to indicate the position of a datum plane and will consist of one long dash and two short dashes evenly spaced.

l. Cutting-Plane and Viewing-Plane Lines. Cutting-plane lines (fig. 94) will be used to indicate a plane in which a section is taken. Viewing-plane lines (fig. 95) will be used to indicate the plane from which a surface is viewed.

m. Thread Depiction. There are various ways of representing threads on a drawing. Figure 96 indicates how outside threads are shown. On the left is shown a thread profile in section; on the right is an ordinary method of showing threads. To save time, a draftsman uses symbols when objects are not drawn to scale. The length of the threaded part is dimensioned, but other necessary information appears in the note, which in this case is 1/4-20 NC-2. The first number, 1/4, indicates the nominal size, which is the outside diameter. The number 20 after the first dash indicates there are 20 threads per inch. The letters NC indicate the thread series, National Coarse. (The two most widely used screw-thread series are the National Coarse (NC) and National Fine (NF) threads. The NF threads have more threads per inch of screw length than the NC). The last number, 2, indicates the class of thread and tolerance, commonly called the fit. If it is a left-hand thread, a dash and the letters LH in bold type will follow the class of thread. Threads without the LH are right-hand threads. Internal threads may also be shown by several kinds of symbols. Here again, it is not necessary to draw the threads when a simple symbol will do just as well. In figure 96, holes A and B will have the same threads as hole C, as indicated by the note. Notice that the threads in the preceding illustration may be screwed into these threaded holes. The note on each one indicates that the threads are exactly the same. Threads may be shown in section, especially in assembly views. Figure 96 clearly shows the relationship of the threaded members. Bolts, studs, and cap-screws are indicated on drawings by outlines and symbols as shown in figure 96.

47. Scale and Size

When possible, drawings are made to the actual size of the object being described. However, it is obvious that many objects are so large that actual size drawings would be impossible to use in a shop. The draftsman, therefore, makes the drawings to some fractional part of the true size of the object. The draftsman enlarges the drawings of small objects. When a drawing of an object is made to its actual size, the drawing is

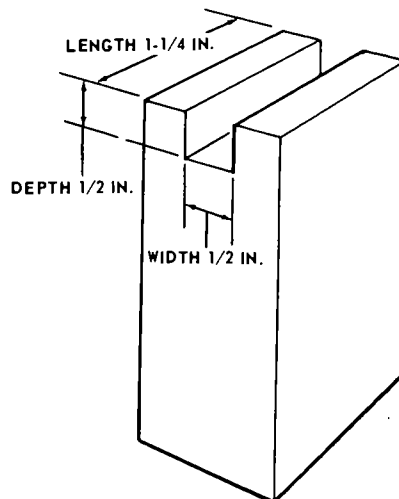
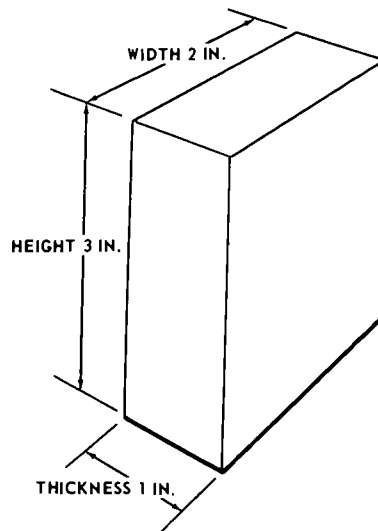
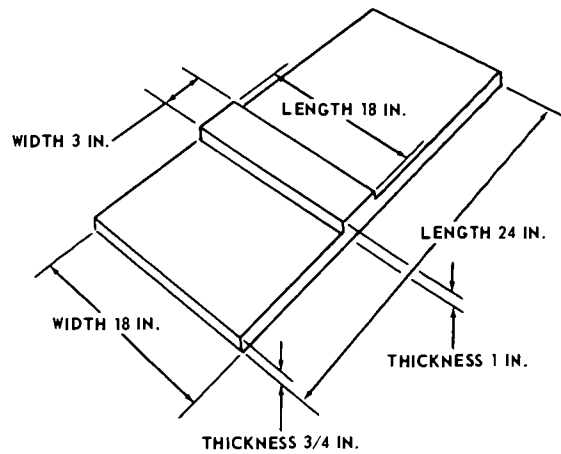


Figure 93. Use of descriptive terms.

known as a full size or full scale drawing. If it is drawn to some fractional part of its true size or enlarged, it is called a scale drawing.

a. *Scale.* The scale to which a drawing is made

is the ratio between the actual size of the drawing and the actual size of the object. The scale used for the drawing should be indicated upon the drawing. This information is usually found in

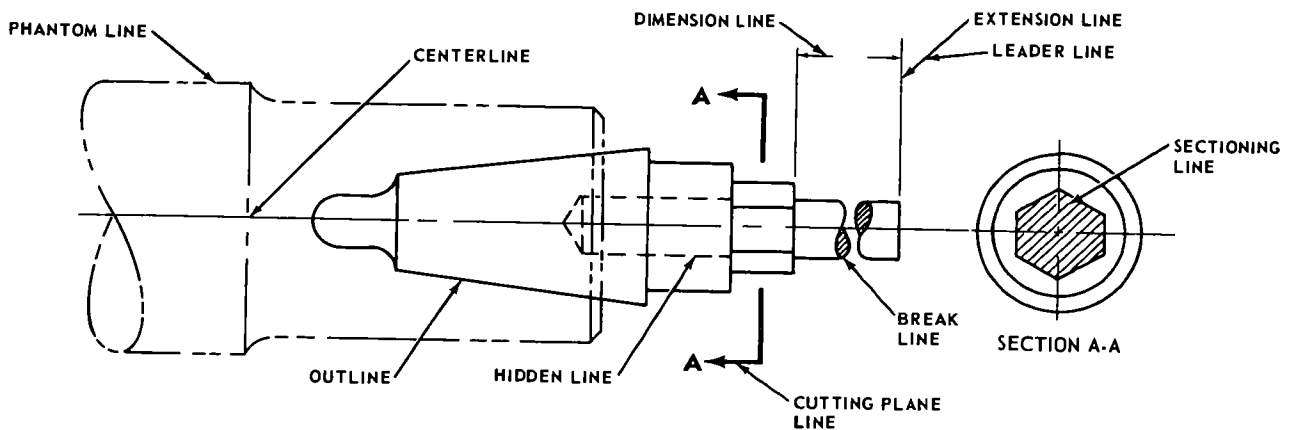


Figure 94. Line conventions.

the title block of the drawing (lower right-hand corner), but may be on the face of the drawing itself. The scales most commonly used are full, three-quarter, half, quarter, and one-eighth. The scale used is indicated upon the drawing in one of many ways. If drawings are made to the actual size of the object, they are indicated as full size or full scale, and so forth. If drawings are made larger than the actual size of the object, they are indicated as twice full size or twice full scale, and so forth.

b. Size. Drawings are made full size when possible, or as nearly so as can be suitably approached. In large aircraft companies where thousands of blueprints are used which, after initial use, are retained for future reference, some thought must be given to their storage and

to the prints made from them. Because of this fact, all drawings are made according to a set of standard sizes. Eight and one-half by eleven inches has become the standard size for most small drawings or blueprints. Larger sized drawings are usually made in some multiple of this size, which permits their being folded to the standard size and stored conveniently. In learning to read blueprints, it should be remembered that drawings or blueprints should never be measured (or scaled, as it is often called). Drawings, when complete, should indicate all dimensions, thus making it unnecessary to measure them. A drawing that is incomplete (one that does not give specific dimensions) should be returned to the drafting or engineering department to be corrected.

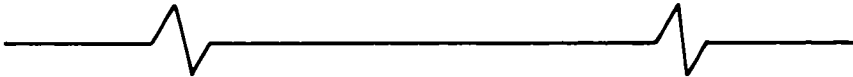
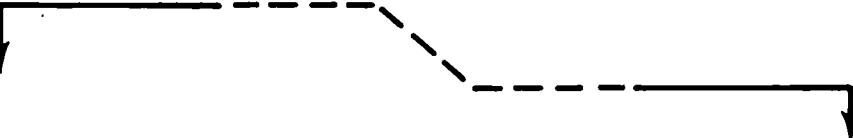
CENTERLINE		THIN
DIMENSION LINE		THIN
LEADER LINE		THIN
BREAK (LONG) LINE		THIN
SECTIONING AND EXTENSION LINE		THIN
PHANTOM AND REFERENCE LINE		MEDIUM
HIDDEN LINE		MEDIUM
STITCH LINE		MEDIUM
DATUM LINE		MEDIUM
OUTLINE OR VISIBLE LINE		THICK
BREAK (SHORT) LINE		THICK
CUTTING-PLANE OR VIEWING-PLANE LINE		THICK
CUTTING-PLANE LINE FOR COMPLEX OR OFFSET VIEWS		THICK

Figure 95. Line characteristics and conventions.

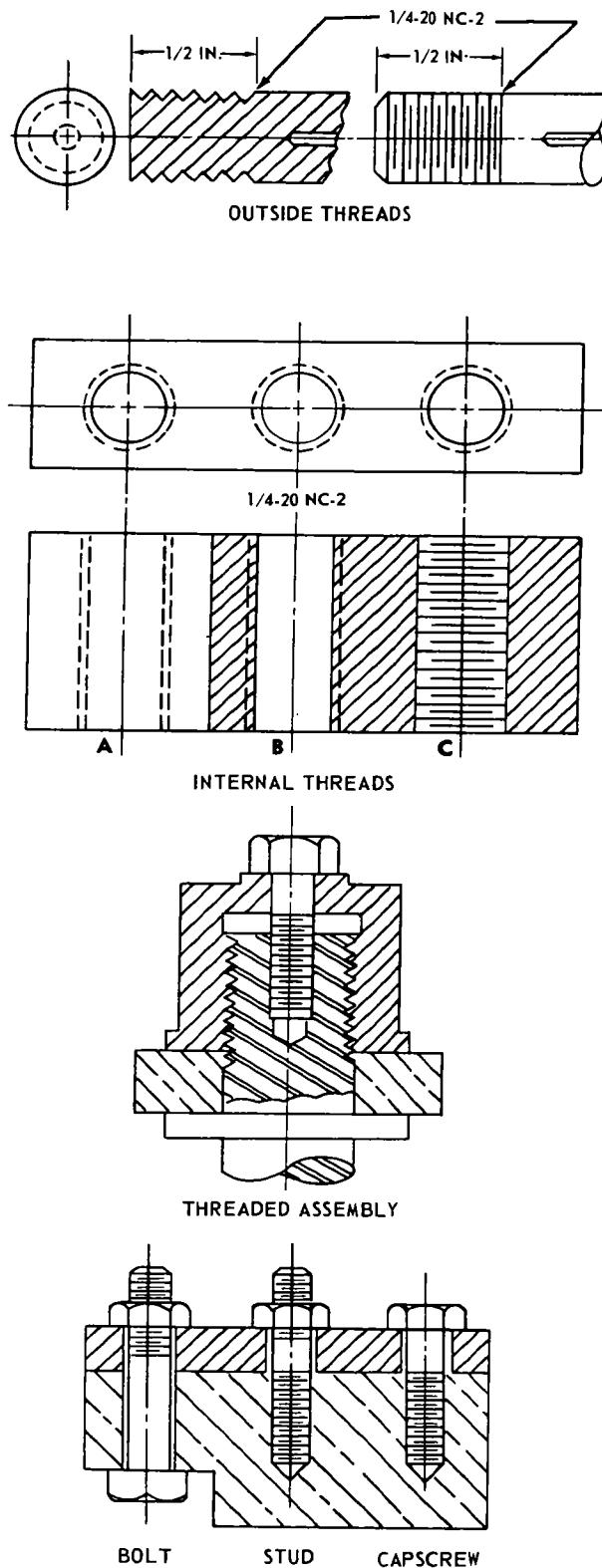


Figure 96. How threads are drawn.

Section III. DIMENSIONING

48. General

After the shape of an object has been described in a view, the value of the drawing for construction of the object depends upon dimensions and

notes to give the description of size. A dimension is used to give the distance between two points, lines, or planes or some combination of points, lines, and planes. The numerical value give the

actual distance, and the dimension line indicates the direction in which the value applies and the points between which the value applies. A note provides a means of giving explanatory information along with the size. The lines and symbols used in dimensioning are—dimension lines, extension lines, numerical values, notes, finish marks, etc.

49. Location of Lines

Draftsmen do not always follow it, but there is a standard procedure for placing dimensions on a drawing. All dimensions and lettering are placed so that they will read from left to right. The dimension of an angle is indicated by placing the degree of the angle in its arc. The dimensions of circular parts are always given in terms of the diameter of the circle and are usually marked with the letter D or the abbreviation DIA following in terms of its radius and is marked with the letter R following the dimension. Parallel dimensions are placed so that the longest dimension is farthest from the outline and the shortest dimension is closest to the outline of the object. On a drawing showing several views, the dimensions will be placed to the best advantage upon each view to show its details.

50. Angles

Angles are dimensioned as shown in figure 97. An arc is drawn and the dimension (degree of the arc) is placed so as to read from a horizontal position. If the angle is too acute to allow space for the dimension, it may be placed as in the example of the 15-degree angle.

51. Small Parts

In the dimensioning of small parts, the available space is often so limited that it prohibits the use of normal size dimensioning lines, symbols,

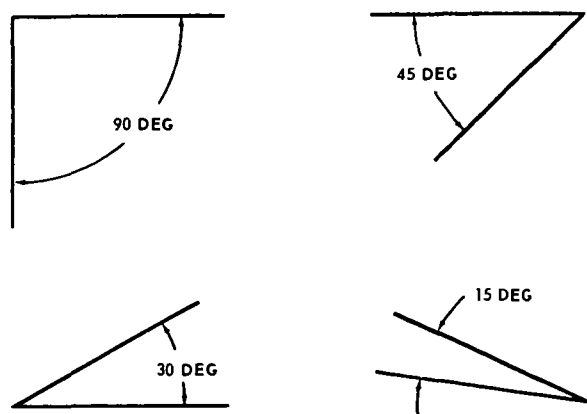


Figure 97. Dimensioning angles.

or figures. In such instances, dimensioning is accomplished by lettering notes or sizes to one side and extending arrows, called leaders, to the small parts (fig. 98). Arrows and figures should always be kept in the clear as much as possible.

52. Tapers

A dimensioning method for an object having inclined or tapered sides is shown in figure 99. Outside dimensions are placed farthest from the object, and inside dimensions are nearest to it. Taper to the foot means the difference in diameter in 1-foot increments in the length of the object.

53. Curves

A curved object may be drawn and dimensioned by using several radii, or by what is known as the offset method. In the offset method, the path of the curve is found by taking a number of measurements from an established line, as AB in figure 100. Dimensions are marked at points indicated by C and at equally spaced points on the object. The distance between the vertical dimensions are given horizontally, as at point D and at similar points.

54. Geometric Solids

In dimensioning spheres, the diameter is given on the view which is most convenient. Ordinarily, only one view of a cone is needed for indicating the diameter and height. The height of a pyramid may be shown on the front view and any other dimensions on a view of the base. The two necessary dimensions of a cylinder, length and diameter, may be shown on one view.

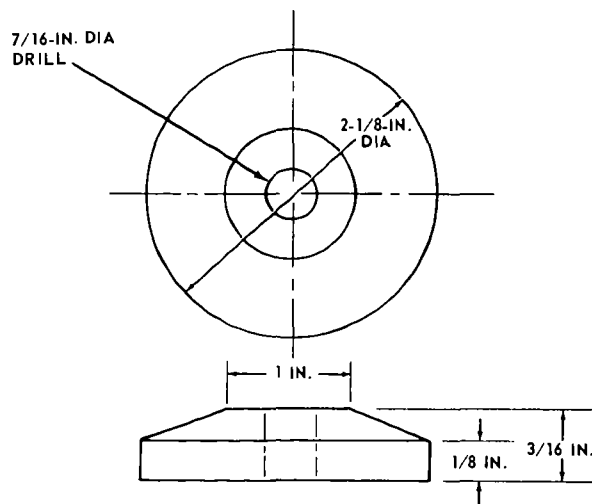


Figure 98. Dimensioning small parts.

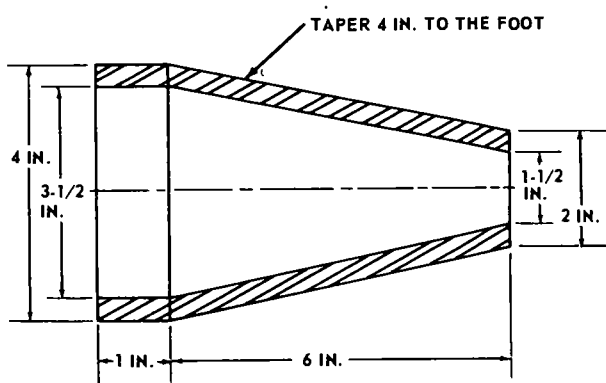


Figure 99. Dimensioning tapers.

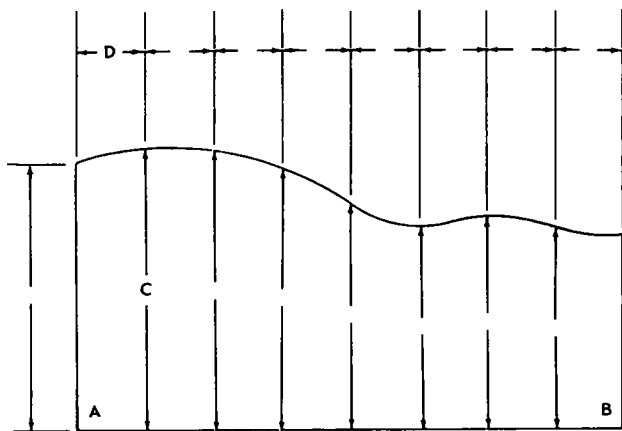


Figure 100. Dimensioning curves.

55. Circles

Diameter dimensions are given for circles, while radius dimensions are given for arcs. Centerlines must not be used as dimension lines; therefore, diameters of circles are sometimes shown by lines within the circle. While this method is approved, a preferred practice is to use extension lines and place the dimensioning outside the circle (fig. 101). Another way is to show the

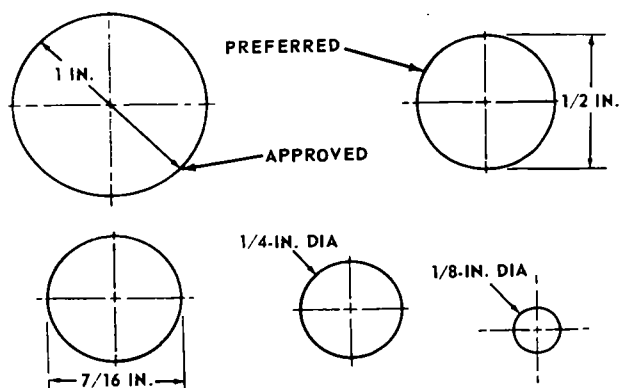


Figure 101. Dimensioning circles.

diameter on a leader at one side with the arrow touching the circumference. This method is better when dimensioning small diameters.

56. Holes

In dimensioning distances between holes in an object, dimensions are usually given from center to center rather than from outside to outside of the holes. When a number of holes of various sizes is shown, the desired diameters are given on a leader followed by notes indicating the machining operations for each hole. If a part is to have three holes of equal size, equally spaced, this information is given. For precision work, sizes are given in decimals. Diameters and depths are given for counterbore holes; for countersunk holes, the angle of countersinking and the diameters are given. Refer to the examples shown in figure 102.

57. Finishes

Dimensions should always give the size of the finished product, regardless of the scale of the drawing. A modified V symbol is used with a number or numbers above it to indicate surface finish (fig. 103). The numbers tell the machinist what degree of finish the surface should have. For a complete description of finish marks, refer to Military Standard MIL-STD-10.

58. Assembly and Detail Dimensioning

The dimensioning of a complicated machine or a large object may at first appear to be a very difficult task. However, if the object is considered as an assembly of small parts, the task becomes relatively simple. There should be information given as to the position these component parts will occupy in relationship to each other. This is done by location dimensioning, which gives the distance from one part to another. Thus, the complete size description of a large object is found to be no more difficult than that of a small one.

59. Tolerance

Tolerance is the amount of allowable variance from a perfect measurement. It is expressed in decimals, usually to at least three places. There are several ways of indicating tolerance on a drawing. With the unilateral method, the minimum or maximum measurement is used as the dimension figure and the difference allowable is given as a plus or minus tolerance figure. See example A in figure 104. In the bilateral method (example B), the dimension figure indicates the plus or minus variation acceptable. In the limit dimensioning method (example C), the maximum and minimum measurements are both

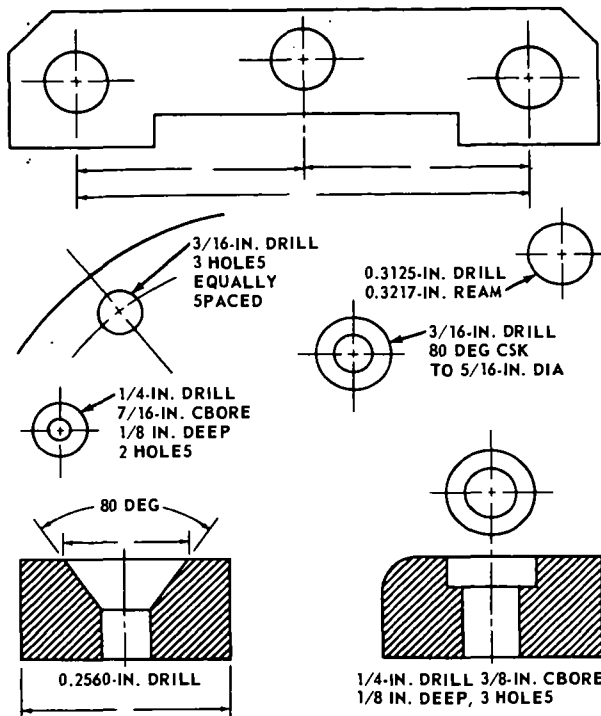


Figure 102. Dimensioning holes.

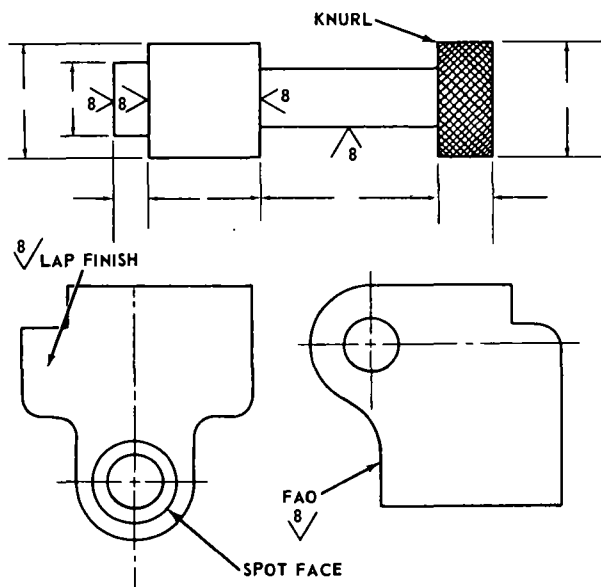


Figure 103. Dimensioning finishes.

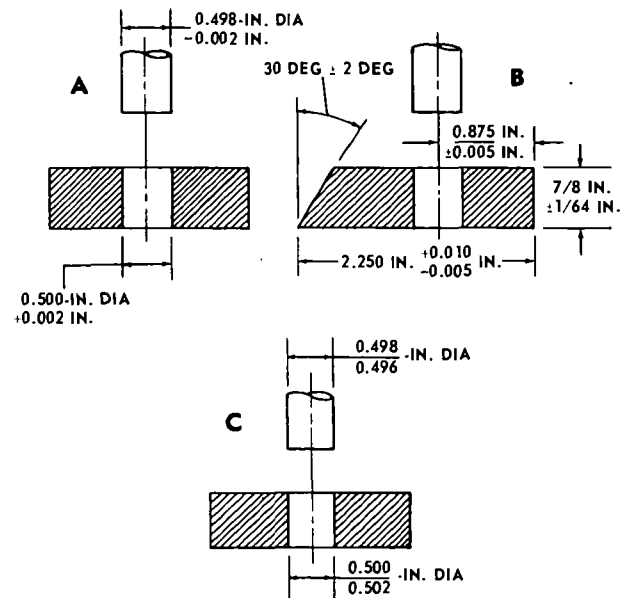


Figure 104. Indicating tolerances.

given. Tolerance dimensions may be specifically given and/or a standard tolerance may apply as indicated in the title block (para 63f).

60. Fits

The dimensions given for fits signify the amount of clearance allowable between moving parts. A positive allowance is indicated for a part that is to slide or revolve upon another part. A negative allowance is one given for a force fit. When possible, the tolerance and allowances for desired fits should conform to those set up in the American Standard for Tolerances, Allowances, and Gages for Metal Fits. The classes of fits specified in the standard may be indicated on assembly drawings.

Section IV. TYPES OF DRAWINGS AND VIEWS

61. Types of Drawings

Note in figure 105 the two different types of drawings of a block. The illustration in the top of the figure is a pictorial drawing, so called because it is similar to the picture of a block. The other views in the bottom of the illustration are called projection drawings because they are projections of the same block. Pictorial drawings

are used only to a limited extent, even though they are more easily understood by those not accustomed to reading drawings. Projection drawings, although more difficult to read and understand, are used almost exclusively to describe objects to be made by repairmen. Pictorial drawings have a distinct disadvantage, as they show the features of an object in a some-

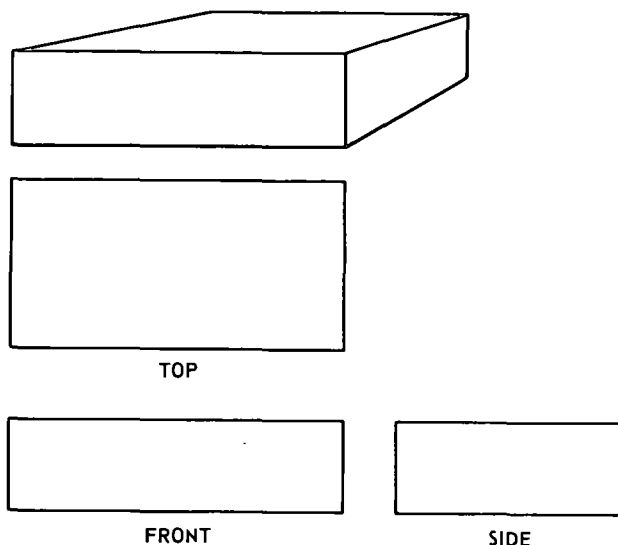


Figure 105. Pictorial and projection drawings.

what distorted way. Projection drawings, on the other hand, have the advantage of showing all the features in their true shape. In comparing the two drawings of the block, note that in the top view the front, top, and one side of the block can be seen connected so that the drawing closely resembles a picture of a block, while in the other view the front, top, and side can be seen definitely outlined, but not directly connected. In the top view, it appears that the angles at the four corners of the front, top, and side of the block are not equal, while in the other view it is found that all the angles are equal.

a. Projection Drawings. A projection drawing of an object shows one principal face and one or more adjoining faces. These adjoining faces are not connected to the principal face. They are drawn directly above or to the left or right. Often, lightweight solid lines are used to almost connect the adjoining faces with the principal face; but they should not actually connect. These lines, called projection lines, are used to locate the position of the same point on an adjoining face or faces. In a projection drawing, each face is represented as though looking directly at that face. The outline of the face as represented on the drawing is called a view. In most projection drawings, it is necessary to show at least two faces or two views of the object. This is done to show the three main dimensions, length, width, and thickness. The view showing the front or principal face is called the front view. It shows that part of the object which would be seen if standing directly in front of the object and looking squarely at it. The front view shows two dimensions, the length running from left to right, and the thickness running from top to bot-

tom. In order to show the remaining dimension, width, at least one additional view must be shown. This dimension, the distance from the front face to the back face of the object, may be shown in either the top or side view. If the draftsman desires to show this dimension in the top view, he merely places the top view directly above the front view. This view then shows the shape and dimensions of the top face as seen by standing directly in front of and looking down upon the top face of the object. This top view shows the distance from the front edge to the back edge of the top, or its width, and also the length which would be shown in the front view. To show width in a side view, the draftsman makes a side or end view directly to the right or left of the front view. This view shows the shape and dimension of the side or end face as seen when looking directly at that face. The side view will show the distance from the front to the back face of an object and the same thickness dimension as shown in a front view.

b. Single-View Drawings. In making drawings of objects to be constructed, a great deal of time and labor can be saved by making only one view of the object, omitting the other two views entirely. The information ordinarily given on the second and third views is usually given in notes accompanying a single-view drawing. Figure 106 shows a single-view drawing of a reinforcement plate. The plate is to be made of sheet stock, and other views would only show the thickness of the stock (0.040 in.) in addition to the length and width which are given in the single view shown. In attempting to show this thickness, the lines representing the two faces would be so close together they would appear as one line. Since a note stating the thickness of the material can be made quickly, it is placed on the single-view drawing. Single-view drawings are used only for objects made of thin material, such as sheet stock, and only then when they are perfectly flat, never when they are bent or curved.

c. Surface Drawings. The face of any solid object is called a surface, and the limits of any

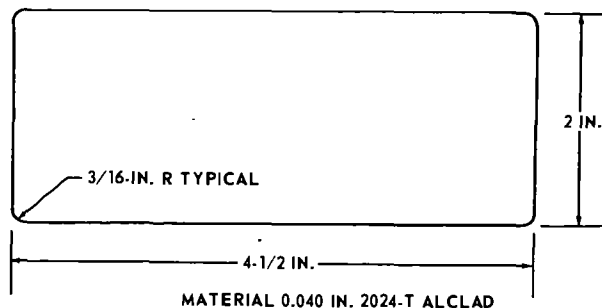


Figure 106. Single-view drawing.

surface on a drawing are indicated by means of lines. A surface has two dimensions, length and width; it has no thickness. When it is necessary to indicate an edge view of a surface, a line is used. Even though the line has thickness, the surface itself does not.

(1) *Number of surfaces.* Study the object in the first of the illustrations in figure 107. It can be seen that the object has six surfaces. These surfaces are usually called the front, back, top, bottom, right side, and left side. Now study the second illustration. The same object is shown with a groove cut in the top surface. Counting the surfaces reveals that there are ten. Examine the third illustration. The same object is shown except that a projection is shown on the bottom. Counting the surfaces reveals that there are now fourteen. It is easy to see from the study of these illustrations that the number of surfaces upon an object can be increased or decreased by changing the shape of one or more of its surfaces.

(2) *Number of views.* Many times it is desirable to make a drawing of three views of an object. This is necessary when it has special features that cannot be shown in two views with sufficient completeness to enable a repairman to construct the object without additional information. For this reason, projection drawings consisting of three views are used. These views are usually the front, top, and either the right or left side views. Another method used in drawings is that of representing features of an object in a view which cannot actually be seen in that view. Such features are indicated by means of dotted lines. This brings to attention the first rule for reading of drawings and blueprints: Solid lines always represent the outline of features which are visible, and lines composed of small uniform dashes always indicate the features which are invisible.

(3) *Six surfaces on three views.* Figure 108 presents the six surfaces of a plan object by showing a view for each surface. Such a drawing, obviously, requires time, labor, and a large piece of paper. For these reasons, a drawing usually presents the six surfaces by three views. This can be done very satisfactorily if the draftsman adheres to the rule which identifies the outline of visible features with solid lines. If the following facts are kept in mind, such drawings will be more readily understood.

(a) The back surface of an object lies directly behind the front surface, and it is customary to represent on the front view all features which are upon the front surface and all features which lie behind the front surface.

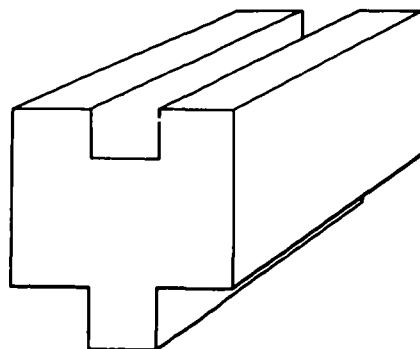
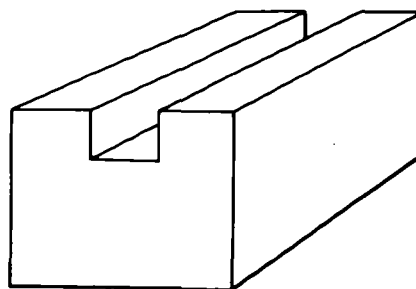
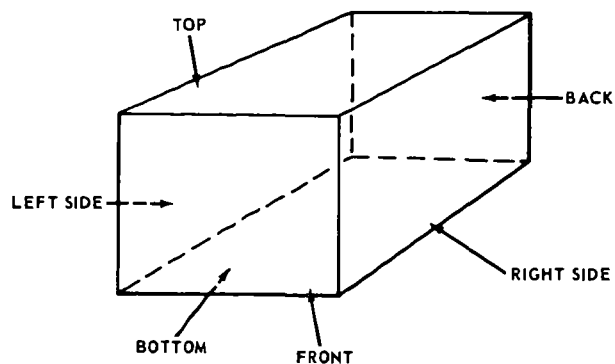


Figure 107. Surface drawing.

Features which are back of the front surface are shown by dotted lines to indicate that they are not visible. However, if a feature which is invisible lies directly back of a visible feature, the two are represented by a solid line.

(b) In the same manner, the bottom surface lies directly below the top surface of an object, and it is customary to represent all features which appear upon the bottom surface with dotted lines in the top view, indicating that they are invisible.

(c) It should be remembered in describing any surface that the person making the description is looking at the center of that surface. As in the top and bottom views and the front and back views, the right side view lies directly back of the left side view or vice versa. In making either side view, the features which are not visible on the surface being described

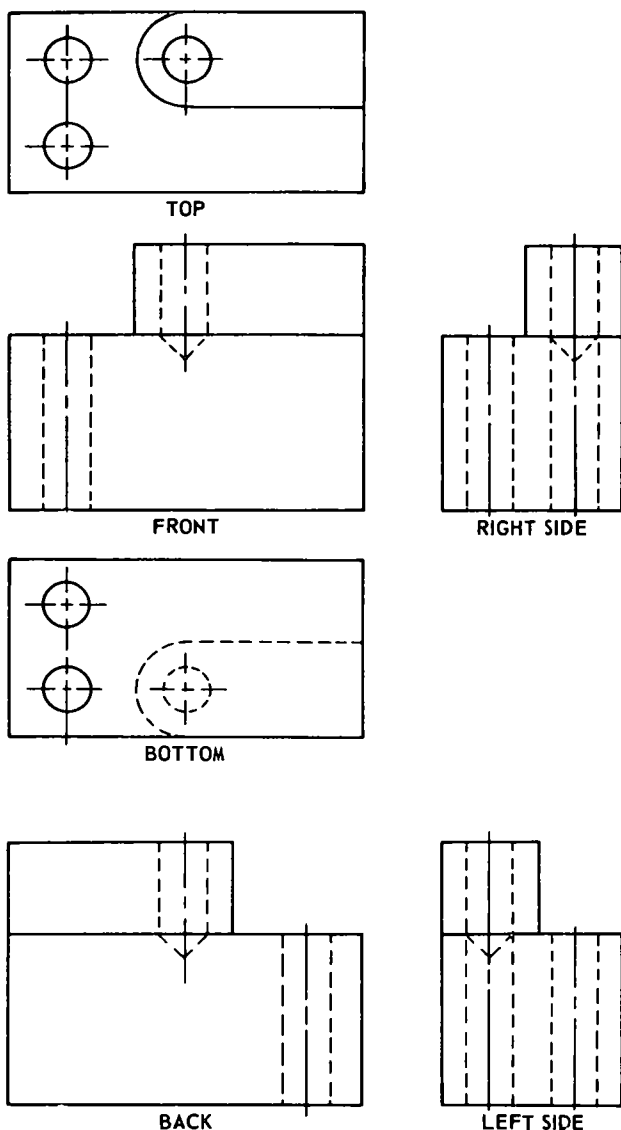


Figure 108. How surfaces are shown.

but which lie back of it, are shown by dotted lines to indicate that they are not visible.

(d) By remembering the above facts, and that an edge of any surface is represented by a line, it can easily be seen that objects with many surfaces may be represented on a three-view drawing without difficulty or confusion.

d. *Working Drawings.* Most drawings are of the projection type; however, some aircraft companies also use pictorial drawings. This is an additional help for the workman in visualizing the objects represented in the projection drawings. In such cases, the pictorial drawings do not give full and complete information concerning the object represented. Instead, they present a representation of the shape and arrangement of the parts of a certain object. Essential information which a person must have in order to make or assemble an object is given on a pro-

jection drawing. Such a drawing gives full and complete information necessary to make or assemble the object represented. It is known as a working drawing. Working drawings must give such information as size of the object and all of its parts, its shape and that of all of its parts, specifications as to the material to be used, how the material is to be finished, how the parts are to be assembled, and any other information essential to making and assembling the particular object. Working drawings are usually divided into three classes: detail drawings, assembly drawings, and installation drawings.

(1) *Detail drawing.* A detail drawing is a description of a single part, given in such a manner as to describe by lines, notes, and symbols the specifications as to size, shape, material, and methods of manufacture which are to be used in making or assembling the object. Detail drawings are usually rather simple; and, when single parts are small, several detail drawings can be shown on the same sheet or blueprint. A detail drawing is shown in figure 109.

(2) *Assembly drawing.* An assembly drawing is a description of an object made up of two or more parts. Examine the assembly drawing in figure 109. It describes the object by giving, in a general way, the size and shape. Its primary purpose is to show the relationship of the various parts. An assembly drawing is usually more complex than a detail drawing, and is often accompanied by detail drawings of various parts.

(3) *Installation drawing.* An installation drawing is one which includes all necessary information for installation of a part or an assembly of parts in the final position in the aircraft. It shows the dimensions necessary for the location of specific parts with relation to the other parts, and reference dimensions which are helpful in later work in the shop (fig. 109).

e. *Sectional Drawings.* Information concerning the interior construction of objects is represented by dotted lines. Dotted lines are adequate for simple drawings, but with more complex drawings it is often difficult to obtain an accurate idea of the interior construction by using only dotted lines. Therefore, draftsmen have developed a method of describing the interior construction of objects by sectional drawings made with solid lines.

(1) *Sectional view.* A sectional view is based upon the assumption that the object has been partially cut or broken away, and the part in front of the break has been removed, thus exposing a view of the interior construction at that point. The new exposed surface is shaded by a series of crosshatch lines. When a sectional view

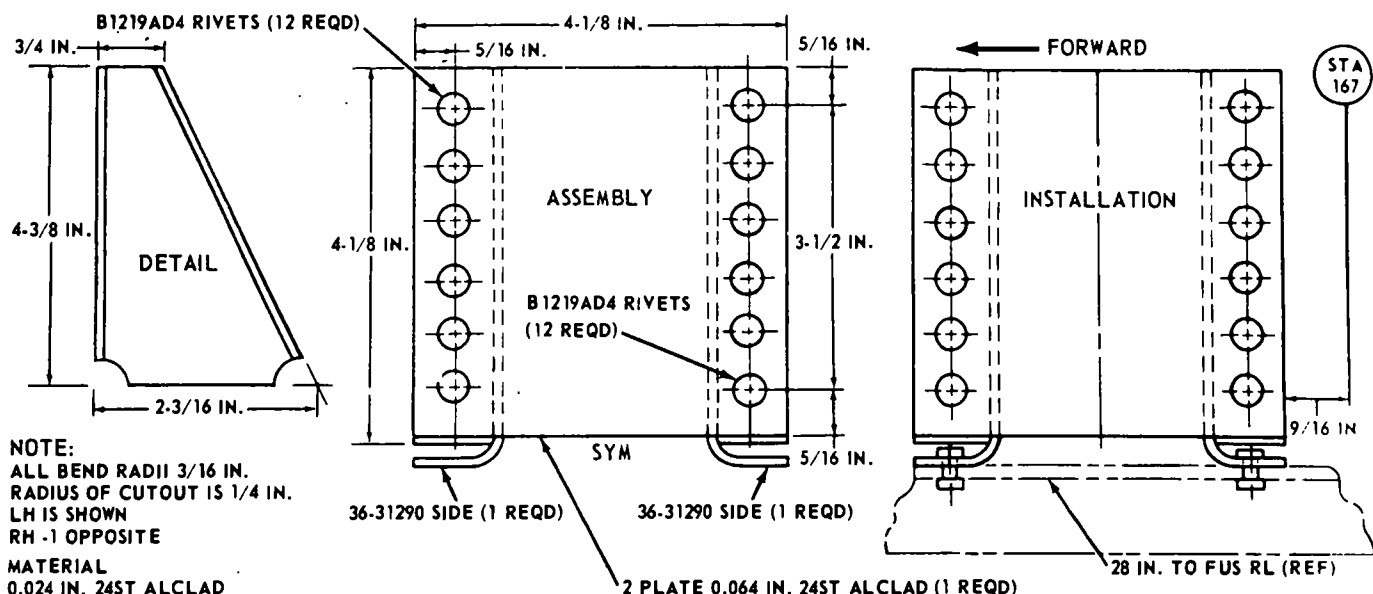


Figure 109. Working drawings.

is made through a solid object such as a nut, bolt, shaft, rivet, or similar part whose axis lies in the cutting plane, the solid part is not cross-hatched.

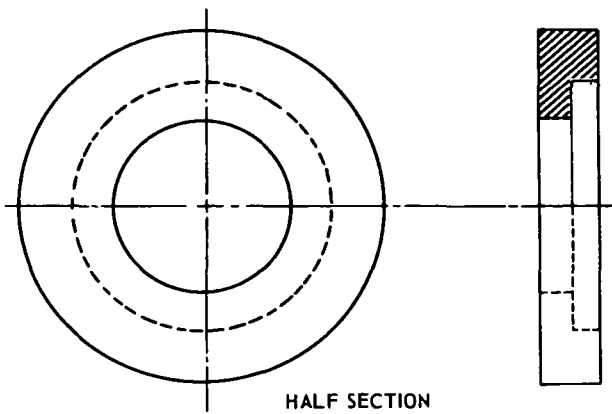
(2) *Kinds of sectional views.* Sectional views as shown in figure 92 are known as full sections; that is, the object is represented as being cut entirely through. At times it is necessary to represent an object as if it were cut only halfway across. The remaining portion would be shown as a regular view. Such a sectional view is used particularly in describing a symmetrical object in which both halves of a full section would be alike. In presenting a sectional view of an object, some view, other than the sectional view, should include a special line called a cutting plane line which indicates the position of the intended cut. Usually this line has arrowheads pointing in the direction in which the section is viewed, as shown in figure 110. Another type of section used quite extensively is the revolved section. This type is used when it is difficult to represent the true shape of a part at a certain point. The revolved section represents the shape of the object, at a particular point, upon the regular view (fig. 110). When it is not possible or convenient to place a revolved section on a drawing in the usual manner, it is placed at any convenient spot on the drawing and is labeled to correspond to the cutting plane line. This type of section is known as a referenced or labeled section (fig. 110). Partial sections are used when it is not desirable to make a complete sectional view. In these instances, the details of the construction may be shown by a section drawn on

the object at the position where it is desirable, as shown in figure 110.

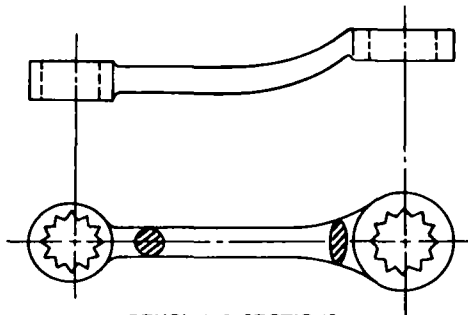
62. Types of Views

A photograph of an object provides a good idea of the shape and the relationship of the various parts, and may show the exact size of the object. What then is the value of a photograph compared to a blueprint? A camera brings all visible parts into one picture view on one plane. It records pictures of objects much the same as human eyes see them. The photograph is deceptive, however, just as the eyes are deceptive. When looking down a straight stretch of railroad track, a person's eyes record that the rails come together at a distant point, but it is known that the rails are parallel; therefore, the eyes cannot be believed. The camera, likewise, would record this deceptive appearance. The lines on a photograph do not register the true length and shape; therefore, photographs cannot be used when accurate blueprints are required. Photographic prints are valuable visual aids when used to show the general location, function, and appearance of parts and assemblies. They are often used to show the special characteristics of parts. Operational steps are often shown by a series or sequence of photo prints. Disassembly and reassembly of a part or unit can be learned by using photographs as a guide.

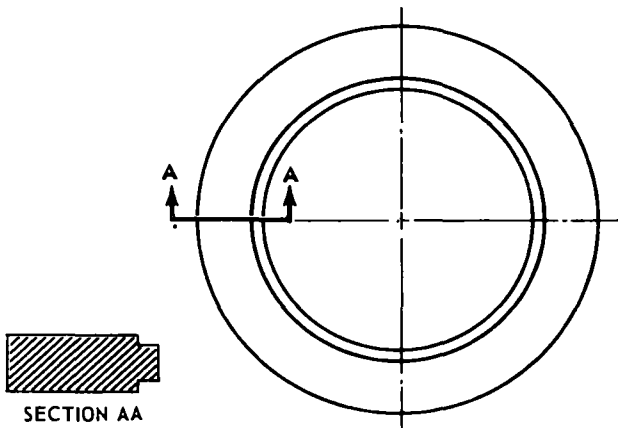
a. Exploded Views. A valuable use of the photograph is for exploded views that show the location of parts. The illustration of a stringer repair in figure 111 is an example of an exploded view. Notice how the parts are spread out to



HALF SECTION

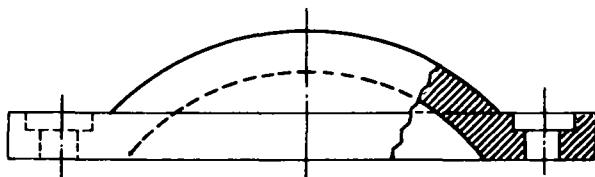


REVOLVED SECTIONS



SECTION AA

REFERENCED SECTION



PARTIAL SECTION

Figure 110. Sectional views.

show clearly each part's relationship to the others.

b. Perspective Views. Perspective views are ex-

cellent substitutes for photographs and may be used in the same manner. They provide a picture of a new type of aircraft or machine before such an article has been manufactured. The draftsman can create such drawings. On a perspective view, lines that are actually parallel on the object would run together if extended on the drawing. In figure 112, notice the length of the right and left wings. They are actually the same length, but if measured on the drawing, one will be found shorter than the other. Although the perspective view provides a picture prior to manufacture, it will not be used in the place of blueprints in construction or repair work.

c. Isometric Views. The isometric view is somewhat like the photograph and the perspective view; however, on the isometric view, lines that are actually parallel on the object would also be parallel on the drawing. All its lines representing horizontal and vertical lines on an object have true length. Vertical lines are shown in a vertical position, but lines representing horizontal lines are drawn at an angle of 30° with the horizontal. Vertical lines and lines representing horizontal lines on such drawings are known as isometric lines. In figure 113, all lines except A and B have true lengths because they are vertical and horizontal lines on the object. Lines A and B are not isometric lines and their lengths are not true. Isometric views have much the same use as other drawings. In addition, they may be dimensioned so that blueprints of these drawings may be used for making simple objects.

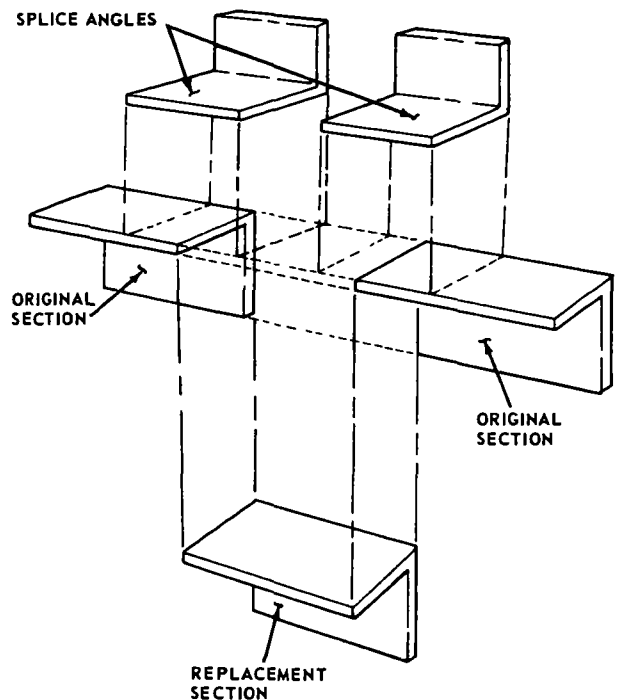


Figure 111. Exploded view.

But isometric views alone cannot be used for complicated parts or structures.

d. Orthographic Views. Blueprints that furnish complete information for construction and repair present an object in its true proportions. Such prints are copies of mechanically drawn orthographic views (fig. 114). These views are accurate and indicate true shape and size. When studying orthographic views, look at one view at a time. To get a good idea of a set of steps, for example, they must be looked at from either the right-hand or left-hand side, then from straight in front and behind, and also from the top. By observing several points a clear understanding of the set of steps can be obtained. This is the basic principle of orthographics. The surface of an object can be seen in its true shape and size only by looking directly at that surface, as shown in the illustration. A person's line of sight must be perpendicular to that surface at all points. When these views of the various surfaces are placed on a drawing, their proper relationship is maintained by the proper arrangement of the views.

(1) *View arrangement.* Study the arrangement of the three views in figure 114. The side view (lower left) is the starting point. It was selected because it shows the most characteristic feature of the object, the step. The front view is projected directly to the right of the side view. Some of the lines on the front view lie along extensions of lines of the side view. Notice that the top view is placed directly above the side view and that some of its lines lie along extensions of lines of the side view. After studying each view, try to visualize the appearance of the object. Think of the object as being immovable, and pretend that you are moving around it. This will help relate the blueprint views to the appearance of the object concerned.

(2) *Auxiliary projection.* Look directly at the front view in figure 115. Notice the inclined surface and how it appears foreshortened rather than its true size. Now look at the right side and top views. They show the true width, but the length appears foreshortened. Since none of these views shows the true shape of the inclined surface, the draftsman uses a special helping view known as an auxiliary. It is obtained by looking directly at the inclined surface.

(3) *Curved surfaces.* Curved surfaces do not always look curved in an orthographic drawing. This is because a person is looking at the top, bottom, or side of an object at 90° to the surface (looking directly at it). Often curved edges are seen which indicate a curved surface behind them; and when the surface itself is seen in another view, it is seen broadside and it appears

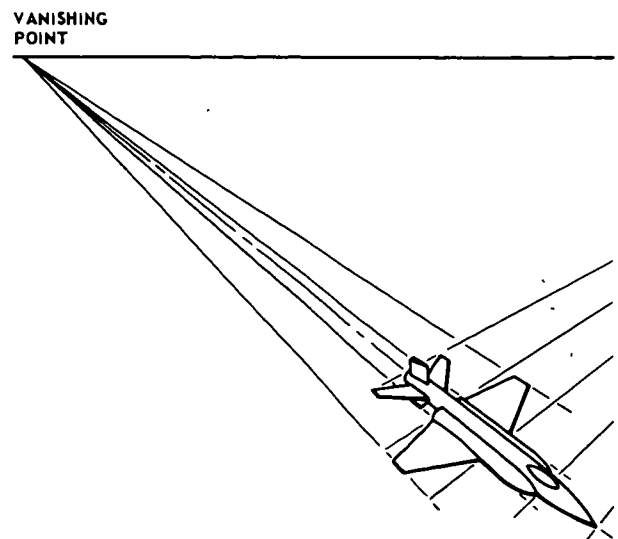


Figure 112. Perspective view.

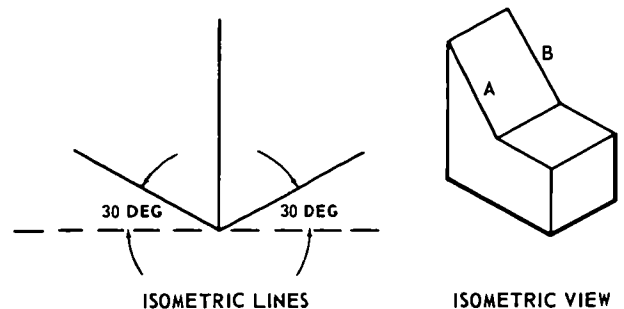


Figure 113. Isometric view.

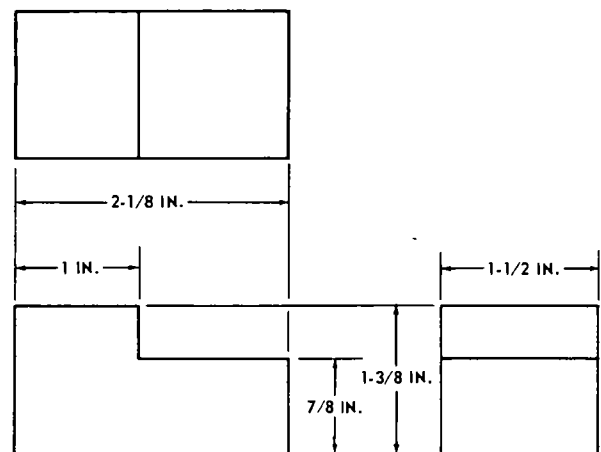


Figure 114. Orthographic views.

flat. The example shown in figure 116 is a two-view orthographic drawing of a cone. It is known that the side of a cone is curved, but the curvature cannot be seen in example B. The bottom edge of this curved side can be seen in example A. It is a good idea to keep in mind the fact that curves in orthographic drawings do not show curved surfaces, but may indicate a curved sur-

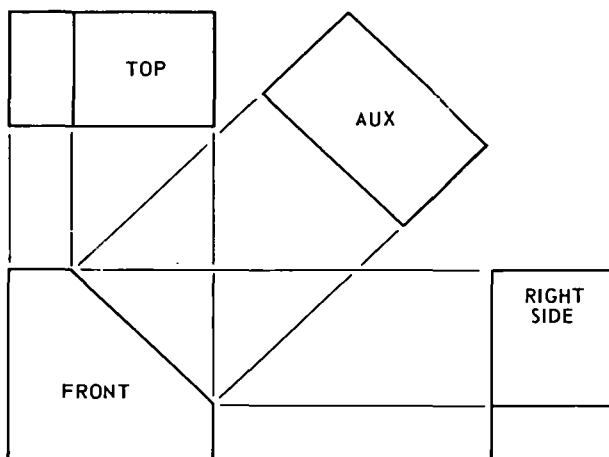


Figure 115. Auxiliary views.

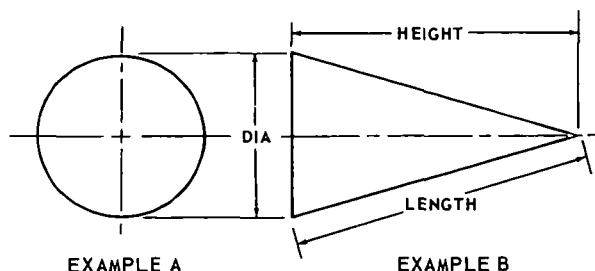


Figure 116. Solid cone.

face behind them. It is up to the individual to find that surface on one of the other views.

Section V. BLUEPRINTS AND USE OF MICROFILM

63. Blueprints

The presentation of an object by the lines of a drawing furnishes the repairman with definite instructions concerning its size and shape. However, it does not give him other necessary information which he must have if the object is to be constructed as it was intended by the draftsman. This additional information, such as the object's name, number, the material from which it is to be fabricated, and possibly other information is essential if the object is to be made correctly. The draftsman must provide this essential information without adding to the complexity of the drawing; yet, it must be placed so that it will be interpreted correctly. Usually, such information is placed in the title block, the change block, or in notes placed so as not to interfere with the drawing itself. It is important that the repairman learn not only where such information is placed, but also how to interpret it. Obtain a military blueprint to use as a guide for the remainder of this paragraph.

a. Title Block. The headlines on the blueprint are in the title block, or box, which is located in the lower right-hand corner of all drawings prepared according to military standards. The title block may appear elsewhere on other blueprints, but the lower right-hand corner is the usual placement. The title block contains the drawing number and all the information required to identify the part or the assembly that the blueprint represents. In approved military blueprints, the title block of the drawing will include the name and address of the government agency that prepared it, the title, the scale, drafting record, authentication, and date.

(1) *Title information.* The portion of the title block which gives the name of the agency

issuing the blueprint and the name and number of the part or assembly is located in the lower right-hand corner of the title block. These items are usually in larger and more prominent letters and figures.

(2) *Next assembly information.* At the right in the title block, just above the number of the part or assembly, will be found three vertical columns having the following identification at the base of each column (reading from right to left): *Model*, *Next Assem*, and *Nr Req Ship*. The information contained in the outside column is the model number of the aircraft which required the part or assembly shown on the blueprint; the middle column contains the number of the assembly into which the part fits; and the left column shows the number of parts required per aircraft.

(3) *Drawing numbers.* All drawings are identified by a drawing number which appears in a number block in the lower right-hand corner of the title block. It may also be shown in other places, such as near the top border line, in the upper right-hand corner, or on the reverse side of the drawing at both ends—so that the number will show when the drawing is folded or rolled. The purpose of the drawing number is for quick identification of a blueprint. If a blueprint has more than one sheet and each sheet has the same number, this information is included in the number block indicating the sheet number and the number of sheets in the series.

(4) *Reference and dash numbers.* Reference numbers that appear in the title block refer to the numbers of other blueprints. When more than one detail is shown on a drawing, dash numbers are used. Suppose that two parts are shown in one detail drawing. Both would have

the same drawing number plus an individual number, such as 40267-1 and 40267-2. In addition to appearing in the title block, dash numbers may appear on the face of the drawing near the parts they identify. Dash numbers are also used to identify right-hand and left-hand parts. In aircraft, many parts on the left side are like the corresponding parts on the right side but in reverse. The left-hand part is always shown in the drawing. The right-hand part is called for in the title block. Above the title block will be found a notation such as: 470204-1LH shown; 470204-2RH opposite. Both parts carry the same number, but the part called for is distinguished by a dash number. Some commercial prints have odd numbers for left-hand parts and even numbers for right-hand parts.

(5) *Scale.* The scale of the drawing is indicated in one space of the title block. It indicates the size of the drawing as compared with the actual size of the part. The scale is usually shown as 1 inch = 2 inches, 1 inch = 12 inches, etc. It may be indicated as full size, one-half size, one-fourth size, and so forth. If the draftsman has used a scale of 1 inch = 2 inches, the object is shown half as large as its actual size. For a scale of 3 inches = 1 inch, the object is drawn three times its actual size. Very small parts are enlarged and large ones are reduced in size to show views clearly. Remember, never measure a drawing; instead, use the dimensions given on the blueprint.

(6) *Heat-treatment.* Most metals require some form of heat-treatment in a manufacturing process. The title block on a blueprint, drawing, or specification lists the type of heat-treatment needed. Frequently it is necessary to remove the temper from a piece of metal so that it can be machined to specifications, after which it is rehardened. Reference is usually to the heat-treatment specifications in the title block.

b. *Bill of Material and Specifications.* A special box on the drawing may contain a list of the pieces of stock necessary to make a part or an assembly of several parts. It is called a bill of material and tells the kind of stock, the size, and the specifications. Many items (such as bolts, screws, turnbuckles, and rivets) have been standardized by the Army, Navy, and Air Force. Each such item has a number with AN or MS in front of it. A wingnut, for example, has a number of AN350. A universal head solid rivet has a number of MS20470. Always use the material specified. The material indicated was selected by an engineer because it meets the requirements of the job it is to perform. It is the best mater-

ial for that particular job. Only an engineer or a person having the authority of an engineer can authorize substitutions of materials when the specified material is not available.

c. *Zone Numbers.* Zone numbers on blueprints are similar to the numbers and letters printed on the borders of a map. They are there to help locate a particular point. To find a point, mentally draw horizontal and vertical lines from the letters and numerals specified; the point where these lines would intersect is the area sought. Use the same method to locate parts, sections, and views on large blueprints, particularly assembly drawings. Parts numbered in the title block can be located on the drawing by finding the numbers in squares along the lower border. Zone numbers read from right to left.

d. *Station Numbers.* A numbering system is used on large assemblies for aircraft to locate stations such as fuselage frames. When *Fuselage Frame-Station 185* is seen, this indicates that the frame is 185 inches from reference datum line of the aircraft. The reference datum line is determined by the manufacturer and may vary forward or aft of the nose on various type aircraft. Refer to the specific technical manual for location of the reference datum line. The same numbering system is used for wing and stabilizer frames.

e. *Finish Marks.* Finish marks are used to indicate the surface that must be machine finished. Such finished surfaces have a better appearance and allow a closer fit with adjoining parts. During the finishing process, the required limits and tolerances must be observed. Do not confuse machined finishes with those of paint, enamel, chromium plating, and similar coating. Drawings prepared according to government specifications require the use of surface roughness symbols. Full explanation for use of these symbols can be found in Military Standard MIL-STD-10.

f. *Tolerances.* When a given dimension on a blueprint shows an allowable variation, the plus figure indicates the maximum and the minus figure the minimum allowable variation. The sum of the plus and minus allowance figures is called tolerance. For example, using 0.225 inch + 0.0025 inch - 0.0005 inch, the plus and minus figures indicate the part will be acceptable if it is not more than 0.0025 inch larger than the 0.225-inch given dimension, or not more than 0.0005 inch smaller than the 0.225-inch dimension. If the plus and minus allowances are the same, they will be presented as 0.224 inch $\pm$ 0.0025. Allowance may be indicated in either fractional or decimal form. When accurate dimensions are necessary, decimal allowances are used. Frac-

tional allowances are sufficient when close dimensions are not required. Standard tolerances of ± 0.010 inch or $\pm 1/32$ inch may be given in the title block of many blueprints to apply throughout the drawing.

g. Usage Block. A usage block may be used to identify, by drawing numbers, the larger unit of which the detail part or assembly shown forms a component part. This block is usually near the title block; or it may form a part of the list of the material block.

h. Change or Revision Block. A revision block is located on the right-hand side of the print. The general practice is to put this space in the upper right-hand corner, but it may be placed above the title if desired. All changes to the drawings are entered in this block and are dated and identified by a number or a letter. If a revision block is not used, a revised drawing may be shown by adding a letter to the original number; for example, 140365-21-A. A indicates the first revision, B the second, etc.

i. Notes. There are times when the person who is to make the object illustrated will need additional information that cannot be placed in either the title or change blocks on the blueprint. In such a case, the information is put on the face of the blueprint in a position which does not interfere with the title block, the change block, or the drawing itself. The information is specific and applies to a particular part or parts. When the note refers to a specific part, a light line with an arrowhead on its distant end leads from the note to the part. If it applies to more than one part, the note is worded so that the individual reading it will make no mistake as to the parts to which it pertains. When there are several notes, they are generally grouped together and numbered consecutively.

64. Use of Microfilm

The practice of recording drawings on microfilm was introduced in recent years. Microfilm

is regular 16-mm or 35-mm film. Since 35-mm film is larger, it provides a better reproduction of drawings. Depending on the size of the drawing to be reproduced, a varying number of drawings can be photographed on one reel of 35-mm film. To view or read drawings on a reel of film, either a portable 35-mm projector or a microfilm reader or viewer is needed. The advantage of microfilm is that several reels, which duplicate perhaps hundreds of drawings, require only a small amount of storage space. Too, a person working on an aircraft may need to refer to a specific dimension. The reel of microfilm can be placed in a projector, the drawing located, and the dimension read. If a detail of the drawing must be studied, or the drawing must be used for a long period of time, an enlarged photographic reproduction can be made, using the microfilm as a negative. Microfilm of drawings has many other uses and advantages. However, microfilm is not intended to replace the need for original drawings, especially where the originals are modified and kept current over long periods of time. When drawings are filmed on continuous reels, corrections can be made by cutting out superseded drawings and splicing in the revised ones. When these corrections become numerous, the procedure becomes impractical and is discarded in favor of again filming the drawings. A method which allows corrections to be made easily, and at any time, is to film the drawings and then cut up the film into individual slides. This has one disadvantage in that it requires considerable time to convert the film into slides, insert them into transparent protective envelopes, and arrange them in sequence so that any desired drawing can be located quickly. A 70-mm microfilm has become available very recently. With it, larger size drawings can be reproduced as individual frames or slides, and these can be inserted in regular paper envelopes and kept in an ordinary file. When held to the light, this large microfilm can be read with the naked eye.

CHAPTER 6

FORMING PROCESS

Section I. GENERAL

65. Shaping Aircraft Metals

a. The shaping of metal material and parts required in aircraft construction by using either machine tools or hand tools (or both) is called forming. Forming may be a very simple process or it may be exceedingly complex, requiring shapes with complex curvature. Large presses, or heavy drop hammers equipped with dies, are used at the factory. Every part is planned by factory engineers who set up specifications for the material to be used, to assure the finished part will have correct temper after it has been formed. A layout of each part is planned by factory draftsmen. The forming process practiced in the repair depot is almost directly opposite in method of procedure as by factory method. However, both methods have much in common, and many of the facts and techniques learned on one process can be applied to the other. Forming is of major concern to the airframe repairman and requires the best of his knowledge and skill. This is especially true since forming usually involves the use of light-gage alloys of a delicate nature, which can be readily made useless by coarse and careless workmanship. A formed part may seem outwardly perfect, yet a wrong step in the forming procedure may leave the part in a strained condition. Such a defect may hasten fatigue or may cause sudden structural failure. Since aluminum and aluminum alloys are the chief metals used in aircraft structure, this chapter deals mostly with the procedures for forming of aluminum and aluminum alloys. However, particulars of stainless steel, magnesium, and titanium that the airframe repairman should know are discussed also.

b. The shaping of metal by exposure to an etching chemical is called chem-milling. It is the application by the manufacturer of an acid to a metal part to lighten and create specifically designed parts of aircraft. The shaping of metal by this method to produce satisfactory results in a complex operation. The use of specific acids, exposure methods, masking templates and highly

trained personnel can produce structural members that would otherwise be impractical. The sequence of chem-milling in relation to mechanical milling normally is determined by part configuration. As a general rule, chem-milling is completed before the part is formed. The use of this method reduces the loss of labor if an error should require scrapping of the part. Refer to paragraph 174f for chem-mill repair fundamentals.

66. Aluminum

Most aluminum parts can be formed without annealing the metal, but if extensive forming operations, such as deep draws (large folds) and complex curves are planned, the metal should be in the dead soft or annealed condition. During the forming of some complex parts, operations may have to be stopped and the metal annealed before the process can be continued or completed. Alloy 2024 in the annealed condition can be formed into almost any shape by the common forming operations, but it must be heat-treated afterward. In forming, use hammer and mallets as sparingly as practicable, and make straight bends on bar folders and cornice brakes. Use rotary machines whenever possible. If a part fits poorly or not at all, do not straighten a bend or a curve and try to reform it. Discard the piece of metal and start with a new one. In making layouts, be careful not to scratch aluminum or aluminum alloys. A pencil, if kept sharp, will be satisfactory for marking. Scribes make scratches which induce fatigue failure; but they may be used if the marking lines fall outside the finished part—that is, if the scribed line will be in the waste material. Keep bench tops covered with material hard enough to prevent chips and other foreign material from becoming imbedded in them. Also, be sure to keep bench tops, clean and free from chips, filings, and the like. For the protection of the metals being worked, keep vise jaws covered with soft metal jaw caps.

67. Stainless Steel

Stainless steel can be formed by any of the usual methods but requires considerably more skill in its forming than aluminum or aluminum alloys. Since stainless steel work-hardens very rapidly, it requires frequent annealing during the forming process. Always try to press out stainless steel in one operation. Use dies where possible in the working of stainless steel. Basic working knowledge of stainless steel should be thoroughly understood by the airframe repairman.

a. Working Stainless Steel. When working with stainless steel, make sure that metal does not get unduly scratched or marred. Also, take special precautions when shearing, punching, and drilling this metal. It takes about twice as much pressure to shear or punch stainless steel as it does to cut mild steel. Keep the shear or punch and die adjusted very closely. Too much clearance will permit the metal to be drawn over the edge of the die and cause it to become work-hardened, resulting in excessive strain on the machine.

b. Drilling Stainless Steel. In drilling stainless steel, use a high-speed drill ground to an included angle of 140° . Some special drills have an offset point while others have a chip curler in the flutes. When using an ordinary twist drill, grind its point to a stubbier angle than the standard drill point. Keep the drill speed about one-half that required for drilling mild steel, but never exceed 750 rpm. Keep a uniform pressure on the drill so the feed is constant at all times. Drill the material on a backing plate, such as cast iron, which is hard enough to permit the drill to cut all the way through the stock without pushing the metal away from the drill point. Spot the drill before turning on the power and also make sure that when the power is turned on, pressure is being exerted. To avoid overheating, dip the drill in water after drilling each hole. When it is necessary to drill several deep holes in stainless steel, use a liquid coolant. A compound made up of 1 pound of sulfur added to 1 gallon of lard oil will serve for this purpose. Apply the coolant to the material immediately upon starting the drill. High-speed portable hand drills have a tendency to burn the drill points and excessively work-harden the material at the point of contact. Because of the temperatures developed by high-speed drill rotation, they should not be used. A drill press, adjustable to speeds under 750 rpm, is recommended.

68. Magnesium and Titanium

a. Magnesium. The airframe repairman should be thoroughly familiar with the following on the working of magnesium:

(1) While magnesium alloys can usually be fabricated by methods similar to those used on other metals, many of the details of shop practice cannot be applied. Magnesium alloys are difficult to fabricate at room temperature; therefore, most operations are performed at high temperatures. This requires preheating of the metal or dies or both.

(2) Magnesium alloy sheets may be cut by blade shears, blanking dies, routers, or saws. Hand or circular saws are usually used for cutting extrusions to length. Conventional shears and nibblers should never be used for cutting magnesium alloy sheet because they produce a rough, cracked edge. Shearing and blanking require close tool tolerances. A maximum clearance of 3 to 5 percent of the sheet thickness is recommended. The top blade of the shears should be ground with an included angle of 45° to 60° . The shear angle on a punch should be 2° to 3° , with a 1-degree clearance angle on the die. For blanking, the shear angle on the die should be 2° to 3° , with a 1-degree clearance angle on the punch. Holddown pressures should be used when possible. Cold shearing should not be accomplished on hard-rolled sheet thicker than 0.064 inch or annealed sheet thicker than $1/8$ inch. Shaving is used to improve the characteristic rough, flaky edges of magnesium sheet which has been sheared. This operation consists of removing approximately $1/32$ inch by a second shearing.

(3) Hot shearing is sometimes used to obtain an improved sheared edge. This is necessary for heavy sheet and plate stock. Annealed sheet may be heated to 600°F . (316°C .), but hard-rolled sheet must be held under 400°F . (204°C .), depending on the alloy used. Thermal expansion makes it necessary to allow for shrinkage after cooling, which entails adding a small amount to the cold metal dimensions before fabrication.

(4) Sawing is the only method used in cutting plate stock more than $1/2$ inch thick. Bandsaw raker-set blades of 4- to 6-tooth pitch are recommended for cutting plate stock or heavy extrusions. Small and medium extrusions are more easily cut on a circular cutoff saw having 6 teeth per inch. Sheet stock can be cut on bandsaws having raker-set or straight-set teeth with a pitch of 8 teeth per inch. Bandsaws should be equipped with nonsparking blade guides to eliminate the danger of sparks igniting the filings.

(5) Cold-working most magnesium alloys at room temperature is very limited because they work-harden very rapidly and do not lend themselves to any severe cold-forming. Some simple bending operations may be performed on sheet

material, but the radius of bend must be at least 7 times the thickness of the sheet for soft material and 12 times the thickness of the sheet for hard material. A radius of 2 or 3 times the thickness of the sheet can be used if the material is heated for the forming operation.

(6) Wrought magnesium alloys tend to crack after they are cold-worked; therefore, the best results are obtained if the metal is heated to 450°F. (232°C.) before any forming operations are attempted. Parts formed at the lower temperature range are stronger because the higher temperature range has an annealing effect on the metal. There are some disadvantages to hot-working. First, heating dies and heating the material is expensive and troublesome. Secondly, there are problems in lubricating and handling materials at these temperatures. However, there are some advantages to hot-working magnesium in that it is more easily formed when hot than are other metals and spring-back is reduced, resulting in greater dimensional accuracy. When heating magnesium and its alloys, watch the temperature carefully as this metal is easily burned. Overheating also causes small molten pools to form within the metal. In either case, the metal is ruined. To prevent burning, magnesium must be protected with a sulfur dioxide atmosphere while being heated. It is permissible to heat small pieces of magnesium with a blowtorch provided proper precautions are exercised. It must be remembered that magnesium will ignite when it is heated to a temperature near its boiling point in the presence of oxygen.

(7) Press or leaf brakes can be used for making bends with short radii. Proper bending around a short radius requires the removal of sharp corners and burs near the bend line. Layouts should be made with a carpenter's soft pencil because any marring of the surface may result in fatigue cracks. Die and rubber methods should be used where bends are to be made at right angles, which complicate the use of a brake. Roll forming may be accomplished cold on equipment designed for aluminum. The most common

method of forming and shallow drawing magnesium is an operation in which a rubber pad is used as the female die. This rubber pad is held in an inverted steel pan which is lowered by a hydraulic press ram. The press exerts pressure on the metal and bends it to the shape of the male die.

(8) The machining characteristics of magnesium alloys are excellent, making possible the use of maximum speeds of the machine tools with heavy cuts and high feed rates. Power requirements for machining magnesium alloys are about one-sixth of those for mild steel.

Note. Filings, shavings, and chips from machining operations should be kept in a covered metal container to overcome any danger of combustion.

Warning: In case of magnesium fire, do not try to extinguish it with water. The oxygen in the water supports the combustion and increases the intensity of the fire. Dry powder is the recommended extinguisher for magnesium fires.

b. Titanium. Titanium was developed to fill the need for a formable, structural sheet material with improved strength-weight properties the intermediate temperature range. Titanium, designated as C-110M, is used in primary structural members, especially those which receive heat from the engine and from aerodynamic heating. It is formed commercially by brakes, stretch formers, hydro presses, drop hammers, and the like, and may be deep-drawn, cupped, beaded, dimpled, or punched. By heating the titanium sheet to 932°F. (500°C.), difficult forming operations can be performed with greater ease, and less springback will occur. For stress relief, heat for 1 hour at 1382°F. (750°C.) and cool uniformly. Titanium sheet can be satisfactorily spot and seam welded. Surfaces must be cleaned completely before welding. Titanium may be flash butt-welded and inert arc welded to itself. It is important that fusion welds be completely surrounded by an inert gas to prevent oxygen-nitrogen pickup. Brazing and soldering techniques have not been fully developed for titanium.

Section II. FORMING OPERATIONS

69. Machine and Hand Bumping

Bumping is the term applied to forming or shaping metal by hammering or pounding. Bumping can only be done on malleable metals, that is, on metals that are capable of being extended or stretched. Bumping can be accomplished either by hand or by machine. During the bumping process, the metal is supported or backed up with a smooth face dolly, sandbag, or die. As the shape of the desired part varies greatly,

many types, sizes, and shapes of dolly blocks and/or dies are used.

a. Machine Bumping. Machine bumping is accomplished by using a power hammer. The operator positions the material to be formed so that the power hammer strikes the desired spot. The anvil or arm supporting the material usually had a convex surface or die so that as hammer blows are applied, the shape is gradually formed.

b. Hand Bumping. Hand bumping is done with

hammers or mallets. Complete instructions for hand bumping are given in paragraph 93a and b.

70. Crimping

The forming on the edges of sheet metal by pleating, folding laps, or corrugating is called crimping. Crimping is often used to make one end of a section of pipe slightly smaller so that it will slip-fit into the plain end of a similar section of pipe. Turning down a flange on a seam or the use of crimping pliers will cause the metal to curve. Some crimping and stretching measures are shown in figure 117.

71. Stretching

The stretching of metal may be accomplished by several methods. On ordinary pieces of flat metal, the most common method is to force the metal outward toward the edges by hammering on areas supported by an anvil or similar base support. As the hammering force is applied, the metal is that area will become thinner. However, since the amount of metal will not have been decreased, it will cover a greater area, which results in stretching at this point. Stretching one portion of a piece of sheet metal affects the surrounding area, especially in the case of formed and extruded angles. For example, hammering the metal in the horizontal flange of the angle strip over a metal block as shown in figure 117 would force the metal to spread; therefore, that section would become longer than the section near the bend. In figure 118, the hammered area of line A has stretched, and the area of line B

has curved. To compensate for the difference in length of the horizontal flange and the vertical flange in this case, the vertical flange, which tends to keep the material near the bend from stretching, would be forced to curve away from the greater length.

72. Shrinking

Shrinking, as the name implies, refers to the reduction of an area of a piece of metal. Thus, the shrinking process is compressing or forcing material into a smaller area. This operation is used to develop curves or straighten flat pieces. For example, if a piece of metal has been stretched too far, the metal must be shrunk to the desired shape. Whereas stretching thins the metal, shrinking increases its thickness. Shrinking on a V-block is shown in figure 119.

73. Folding (Bending)

Making bends in sheets, plates, or leaves is called folding. Folds are usually thought of as sharp, angular bends. They are generally made on folding machines.

a. When making bends consider the thickness of the material, its alloy composition, and its temper conditions. The thinner the metal, and also the softer the metal, the sharper the bend can be made.

b. Tables and formulas are used to determine the necessary steps to take in folding material. All these tables and formulas are based on the decimal system. If the sheet stock thicknesses are given in gage numbers, they must be converted to their decimal equivalent.

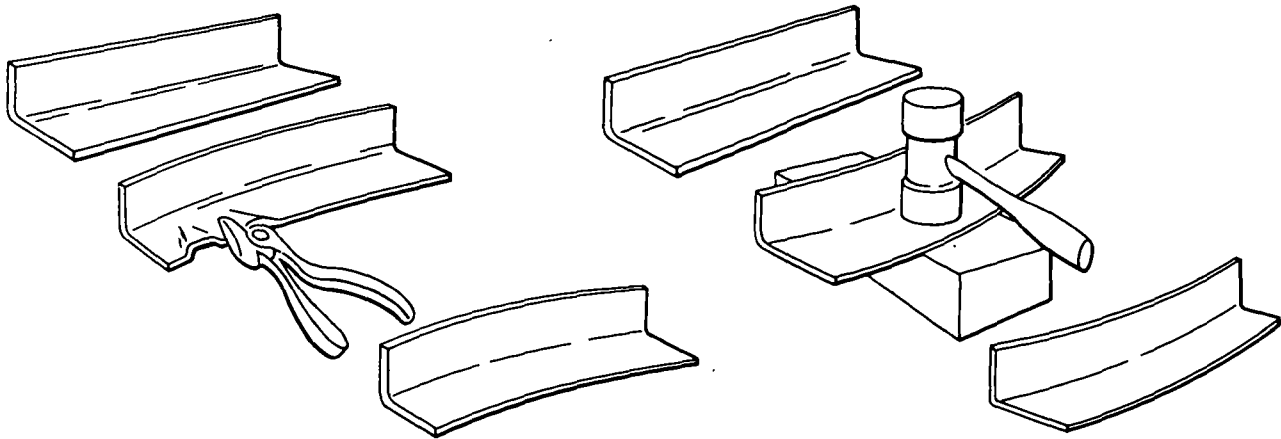


Figure 117. Crimping and stretching.

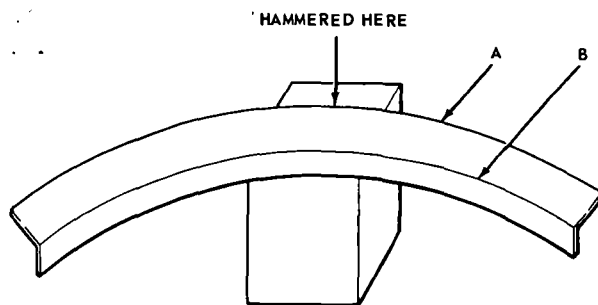


Figure 118. Stretching in a curve.

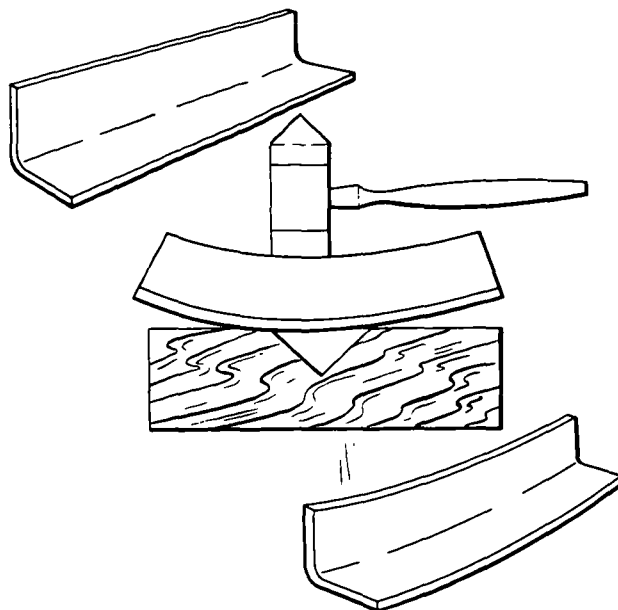


Figure 119. Shrinking on a V-block.

Section III. FORMING TERMS

74. Radius

a. *Radius of Bend.* The term radius of bend, used when the forming of a bend in sheet metal is in progress, is the measurement on the inside of the curved portion of material. The radius of bend is always to the inside of the material unless otherwise stated (fig. 120).

b. *Bend Allowance.* In making folds or bends in sheet metal, necessary allowance must be made for the expansion and contraction of the material at the bend. The outside portion of the metal tends to stretch, while the inside portion tends to compress. Bend allowance is known as the amount of sheet metal required to make a bend over a given inside radius. It takes less metal

to form a curved angle or area than forming a square angle area. The airframe repairman must know how to lay out and cut the sheet metal in this case. Bend allowance depends upon four factors: the degree of bend, the radius of bend, the thickness of the metal, and type of metal (fig. 120).

75. Minimum Bend Radius

The minimum bend radius is the sharpest curve, or bend, that can be applied to a piece of material in the bend area. If the radius of bend is too small, stresses and strains will weaken the metal and may result in cracking. The minimum radius is specified in table 24 for various thickness range of metal. The kind of metal, thickness, and temper conditions of the sheet metal are affecting factors. Annealed sheets can be bent to a radius approximately equal to its thickness. Stainless steel and 2024-T aluminum alloy require a fairly large bend radius.

76. Degree of Bend

The term degree of bend is used to identify the formed position of the material from parallel. The degree of the bend or fold can be any degree from 1° up to, and including, 360°. The shape could be an angle or a curve. Ducting, tubing, and piping are examples of a 360-degree bend.

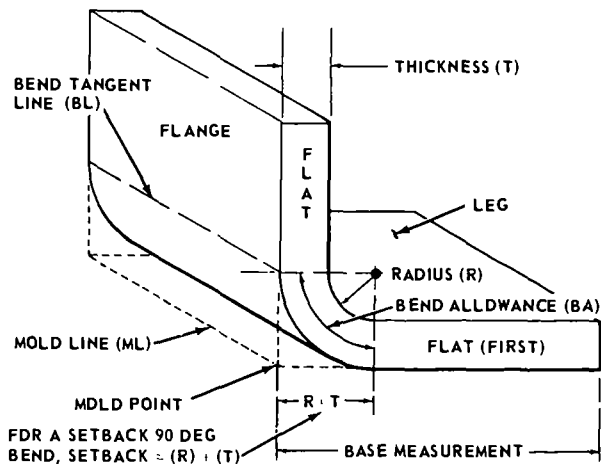


Figure 120. Bend allowance terms.

Table 24. Minimum Allowable Bend Radii

Annealed steel sheet			Annealed aluminum alloy		Heat-treated aluminum alloy	
USS gage (in.)	Minimum radius (in.)	Gage (in.)	Minimum radius		Minimum radius	
			Standard (in.)	Special (in.)	Standard (in.)	Special (in.)
0.025	1/32	0.016	1/64	----	3/32	3/64
0.031		0.020				
0.038		0.025				
0.050	1/16	0.032	1/32	1/64	1/8	1/16
0.063		0.040				
0.078	1/8	0.051	1/16	1/32	3/16	3/32
0.094		0.064	1/8	1/16	1/4	1/8
0.125		0.072	1/4	3/32	1/4	----
0.188	3/16	0.081	1/4	3/32	9/32	----
0.250	1/4	0.091	5/32	3/32	5/16	----
		0.102	3/16	3/32	3/8	----
		0.125	1/4	1/8	1/2	----
		0.156	5/8	5/32	5/8	----
		0.188	3/4	3/16	3/4	----
		0.250	1/2	1/4	1	----

The special minimum radii for aluminum alloy sheet may be used where the bend is 90° or less in special cases, as for example where clearance for rivet or bolt heads or attached parts is necessary.

77. Bend Tangent Line and Base Measurement

a. *Bend Tangent Line.* The bend tangent line is the line at which the metal starts to bend (fig. 120).

b. *Base Measurement.* The base measurement is the outside dimensions of a formed part (fig. 120).

78. Setback

In forming curves or angles on pieces of sheet metal, it is necessary to know the starting and ending points of the bend in order that the length of the flat stock can be determined. Two factors are important in determining this: the radius of the bend and the thickness of the material. The sum of these two factors is called setback, which is subtracted from the overall measurement for final layout dimensions (fig. 120).

79. Mold Point (or Mold Lines)

The mold point is the point of intersection of lines extending from the outside surfaces of the material at each end of the bend. In figure 120, note that the bend tangent lines are the starting and ending points of the bend.

80. Neutral Axis or Neutral Line

In folding or bending, the sheet metal is compressed on the inside and stretched on the outside of the fold or bend. Approximately halfway between these two extremes lies a portion that is not affected by this action; it neither shrinks nor stretches, but retains the same shape. This is known as the neutral axis or neutral line. It occurs at a distance of approximately 0.445 percent of the metal thickness (0.445 X T) from the inside of the radius of bend (fig. 121).

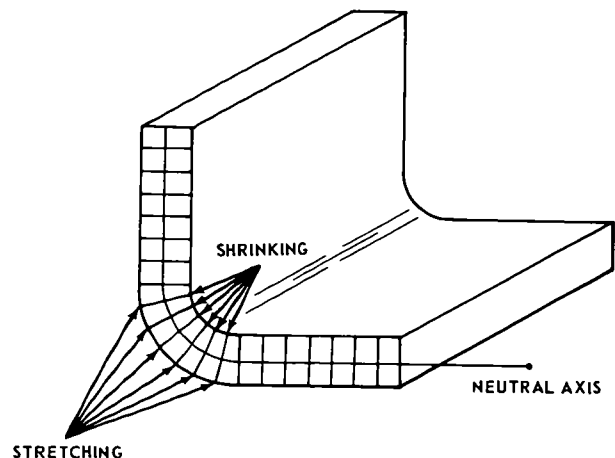


Figure 121. Neutral axis.

Section IV. STRAIGHT LINE BENDS OR FOLDS

81. Bend Allowance

The accepted practice in aircraft construction and repair is to form flanges or bends with a radius that will leave the formed material shape as strong as the original shape. Sheet metal that has been formed to a sharp angle is not as strong as when it has been shaped to a rounded corner. The sharply bent piece will have the stresses

concentrated at the bend. Even though most aircraft sheet metal are malleable, they will crack if bent too sharply. All aircraft metals cannot be bent to the same radius. The minimum radius depends on both the temper and the thickness of the metal. The radius of the bend is generally proportional to the thickness of the material. The type of material is also important, for if

the material is soft it can be bent very sharply; if it is hard, the radius of bend will have to be greater and the bend allowance greater. The degree of bend will affect the overall length of the metal, whereas the thickness influences the radius of bend. When bending metal to exact dimensions, the length of the neutral line must be determined in order that sufficient material can be allowed for the bend. To save the airframe repairman time in making calculations of bend allowances, formulas and tables (charts) have been established as described in the following subparagraphs:

a. *Formula.* Figure 122 illustrates a piece of material bent 360°. Engineering experiments have determined that the bend allowance for a 360-degree bend is $2\pi(R + 1/2T)$ or $2\pi R + \pi T$, where

R = Radius, and

T = Thickness of material

In order to use this formula for any degree of bend, the bend allowance for 1° must be found. Therefore, the bend allowance for a 1-degree bend would be

$$\frac{2\pi R + \pi T}{360} \text{ or } 0.01745R + 0.0087T.$$

Although this formula is theoretically correct, it is inaccurate because the neutral axis is not exactly in the center of the material. Refer to paragraph 80. Through experimentation, it was found that accurate results could be obtained with a slight change in the formula. The corrected formula for all bends ranging from 1° to 180° is—

$$BA = (0.01743R + 0.0078T)N$$

where

BA = Bend allowance,

R = the desired bend radius,

T = thickness of material, and

N = number of degrees of bend.

Example: Find the bend allowance for a 90-degree bend having a radius of 0.250 inch for material 0.051 inch in thickness.

Substituting in the formula

$$BA = (0.01743R + 0.0078T)N \text{ would give:}$$

$$BA = (0.01743 \times 0.250 + 0.0078 \times 0.051) \times 90$$

$$= (.043575 + 0.0003978) \times 90$$

$$= 0.00476 \times 90 = 0.428 = BA \text{ for } 90^\circ$$

b. *Bend Allowance Table.* In table 25, radius of bend is given as a decimal fraction on the top line. Bend allowance is given directly below the radius figures. The top number in each case is the bend allowance for a 90-degree angle, while the lower placed number is for a 1-degree angle. Material thickness is given in the left column of the table. As an example, find the bend allowance when the sheet thickness is 0.051

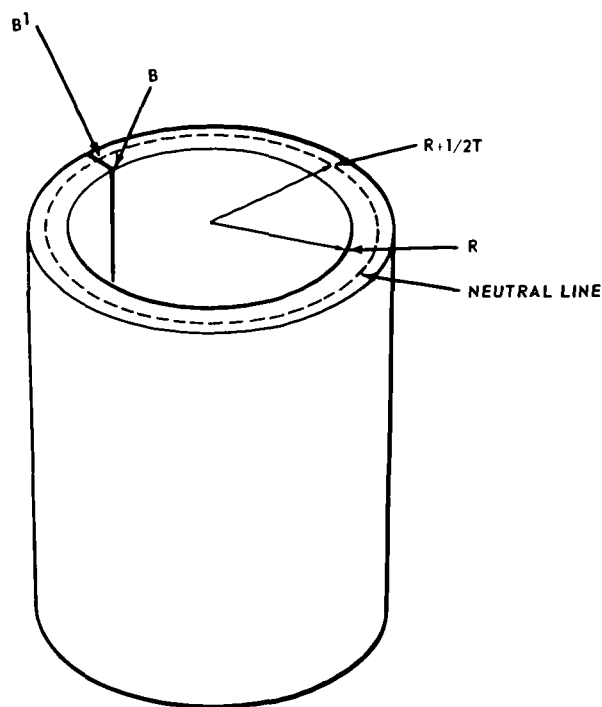


Figure 122. A 360-degree bend.

inch, the radius of bend is 1/4 inch (0.250 in.), and the bend is to 90°: Reading across the top of the table, find the column for a radius of bend of 0.250 inch. Now find the block in this column that is opposite the gage of 0.051 in the column at left. The upper number in the block is 0.428, the correct bend allowance in inches for a 90-degree bend. If the bend is to be other than 90°, the lower number in the block (the bend allowance for 1°) must be used and the bend allowance computed. The lower number in this case is 0.004756. Therefore, if the bend is to be 120°, the total bend allowance in inches will be 120×0.004756 , or 0.5707 inch.

82. Setback

When folding or bending metal, it is often necessary to know the exact starting and ending points of the fold or bend. To accurately locate these points, not only must the bend allowance be determined, but also the length of the flat portions. In order to determine the length of the flats, the setback must be found and subtracted from the base measurement (fig. 120). Two factors are important in determining setback: the radius of bend (R) and the thickness of the sheet metal (T). In figure 123, note that the setback is the distance from the bend tangent line to the mold point and that setback is the same for the vertical flat and the horizontal flat.

a. *Formula.* Setback for all 90-degree bends can be calculated from the formula

$SB = R + T$, where

SB = Setback,

R = Radius, and

T = Thickness of metal.

For example, for a piece of 0.03 inch thick material which is to be bent to a radius of 1/8 inch (0.125 in.):

$$SB = 0.125 + 0.032 = 0.157 \text{ inch.}$$

When setback is subtracted from the base measurement, the remainder will be the length of the first flat, which may be laid out on the sheet metal. Next, calculate the bend allowance. This value is then added to the length of the flat and the sum is the length of metal required for the first flat and the bend.

b. *K-Chart*. To calculate setback for bends, other than 90°, a setback K-chart (table 26) must be consulted for a value called K and substituted in the formula $SB = K(R + T)$. For example, the K value for a 120-degree bend given in table 26 is 1.7320.

83. Locating Brake or Sight Line

The brake or sight line is the mark on a flat sheet which is set even with the nose of the radius bar of the cornice brake. Figure 124 shows the brake or sight line in relation to the position of the material and radius bar. The brake or sight line serves as a guide in bending. The location of the brake line can be determined by measuring out one radius from the bend tangent line which is to be inserted under the nose of the cornice brake or against the radius form block.

84. Simplified Shop Method of Applying Setback and Bend Allowance

a. *Simple Flat Layout Method*. This method may be used for the majority of aircraft fabrication involving bending. It is applicable to only those 90-degree bends whose radii are equal to approximately one, two, or three times the thickness of the material. For example if R equals 3/32 inch (0.0937 in.), and t equals 0.051 inch, then the radius is approximately two times the thickness of the metal and can be stated as $R = 2t$. In using this method, the end of the sheet closest to the bend line must be inserted into the brake. The distance the bend line is located from the end of the sheet is equal to

the inside height of the flange or leg. Figure 125 illustrates the dimensions for a flanged job which can be laid out by the Simple Flat Layout Method. $R = 0.125$ inch (i.e., $R = 3t$) $t = 0.040$ inch.

- (1) Determine inside dimensions.

$$\text{Inside height} = 1.000 \text{ inch} - t.$$

$$\text{Inside height} = 1.000 \text{ inch} - 0.040 \text{ inch.}$$

$$\text{Inside height} = 0.960 \text{ inch.}$$

$$\text{Inside width} = 3.000 \text{ inch} - 3t.$$

$$\text{Inside width} = 3.000 \text{ inch} - 0.120 \text{ inch.}$$

$$\text{Inside width} = 2.880 \text{ inch.}$$

- (2) Determine overall length, as shown in figure 125.

$$\text{Overall length} = 0.960 \text{ inch} + 2.880 \text{ inch} + 0.960 \text{ inch.}$$

$$\text{Overall length} = 4.80 \text{ inch or } 4\frac{51}{64} \text{ inch.}$$

(3) Each bend is made by inserting the end of the metal under the jaw of the brake so that the bend line, which has been marked on the sheet with a soft-lead pencil, will be directly under the nose of the brake, as demonstrated in figure 126. The bend line is 0.960 inch from the end of the sheet, as shown in figure 125.

b. *Radius Acquired by Affixing Mandrels to Jaw of Brake*. After the layout has been made on the material, the metal may be bent by cornice brake, bar folder, or form blocks. In each case, the radius of the part over which the metal is to be bent must be the same as the radius required. Various mandrels or dies can be used to perform this work. Exact results can be obtained in the cornice brake by using mandrels or dies (sometimes referred to as radius bars) which may be attached to the lower side of the clamping jaw of the brake. If radius bars are not available, pieces of sheet aluminum should be formed to radius desired and clamped over the jaw of the brake. Regardless of the method of bending, the metal must be held so that the bend begins at the bend tangent line. Figure 126 shows the bend line location in relation to the mandrel and jaw of brake. Be sure that the metal sheet is placed so that the nose of the brake will fall directly over the bend line.

Table 25. Bend Allowance Table

T \ R	1/32	1/16	3/32	1/8	5/32	3/16	7/32	1/4	9/32	5/16	11/32	3/8	7/16	1/2
0.020	0.031 0.062 0.000693	0.063 0.113 0.001251	0.094 0.161 0.001792	0.125 0.210 0.002333	0.156 0.259 0.002874	0.188 0.309 0.003433	0.219 0.358 0.003974	0.250 0.406 0.004515	0.281 0.455 0.005056	0.313 0.505 0.005614	0.344 0.554 0.006155	0.375 0.603 0.006695	0.438 0.702 0.007795	0.500 0.799 0.008877
0.025	0.066 0.000736	0.116 0.001294	0.165 0.001835	0.214 0.002376	0.263 0.002917	0.313 0.003476	0.362 0.004017	0.410 0.004558	0.459 0.005098	0.509 0.005657	0.558 0.006198	0.607 0.006739	0.705 0.007838	0.803 0.008920
0.028	0.068 0.000759	0.119 0.001318	0.167 0.001859	0.216 0.002400	0.265 0.002941	0.315 0.003499	0.364 0.004040	0.412 0.004581	0.461 0.005122	0.511 0.005680	0.560 0.006221	0.609 0.006762	0.708 0.007862	0.805 0.008944
0.032	0.071 0.000787	0.121 0.001345	0.170 0.001886	0.218 0.002427	0.267 0.002968	0.317 0.003526	0.366 0.004067	0.415 0.004608	0.463 0.005149	0.514 0.005708	0.562 0.006249	0.611 0.006789	0.710 0.007889	0.807 0.008971
0.038	0.075 0.000837	0.126 0.001396	0.174 0.001937	0.223 0.002478	0.272 0.003019	0.322 0.003577	0.371 0.004118	0.419 0.004659	0.468 0.005200	0.518 0.005758	0.567 0.006299	0.616 0.006840	0.715 0.007940	0.812 0.009021
0.040	0.077 0.000853	0.127 0.001411	0.176 0.001952	0.224 0.002493	0.273 0.003034	0.323 0.003593	0.372 0.004134	0.421 0.004675	0.469 0.005215	0.520 0.005774	0.568 0.006315	0.617 0.006856	0.716 0.007955	0.813 0.009037
0.051		0.134 0.001413	0.183 0.002034	0.232 0.002575	0.280 0.003116	0.331 0.003675	0.379 0.004215	0.429 0.004756	0.477 0.005297	0.527 0.005855	0.576 0.006397	0.624 0.006934	0.723 0.008037	0.821 0.009119
0.064		0.144 0.001595	0.192 0.002136	0.241 0.002676	0.290 0.003218	0.340 0.003776	0.389 0.004317	0.437 0.004858	0.486 0.005399	0.536 0.005957	0.585 0.006498	0.634 0.007039	0.732 0.008138	0.830 0.009220
0.072			0.198 0.002202	0.247 0.002743	0.296 0.003284	0.336 0.003842	0.394 0.004283	0.443 0.004924	0.492 0.005465	0.542 0.006023	0.591 0.006564	0.639 0.007105	0.738 0.008205	0.836 0.009287
0.078			0.202 0.002249	0.251 0.002790	0.300 0.003331	0.350 0.003889	0.399 0.004430	0.447 0.004963	0.496 0.005512	0.546 0.006070	0.595 0.006611	0.644 0.007152	0.745 0.008252	0.840 0.009333
0.081			0.204 0.002272	0.253 0.002813	0.302 0.003354	0.352 0.003912	0.401 0.004453	0.449 0.004969	0.498 0.005535	0.548 0.006094	0.598 0.006635	0.646 0.007176	0.745 0.008275	0.842 0.009357
0.091			0.212 0.002350	0.260 0.002891	0.309 0.003432	0.359 0.003990	0.408 0.004531	0.456 0.005072	0.505 0.005613	0.555 0.006172	0.604 0.006713	0.653 0.007254	0.752 0.008353	0.849 0.009435
0.094			0.214 0.002374	0.262 0.002914	0.311 0.003455	0.361 0.004014	0.410 0.004555	0.459 0.005096	0.507 0.005637	0.558 0.006195	0.606 0.006736	0.655 0.007277	0.754 0.008376	0.851 0.009458
0.102				0.268 0.002977	0.317 0.003418	0.367 0.004076	0.416 0.004617	0.464 0.005158	0.513 0.005699	0.563 0.006257	0.612 0.006798	0.661 0.007339	0.760 0.008439	0.857 0.009521
0.109				0.273 0.003031	0.321 0.003572	0.372 0.004131	0.420 0.004672	0.469 0.005213	0.518 0.005754	0.568 0.006312	0.617 0.006853	0.665 0.007394	0.764 0.008493	0.862 0.009575
0.125				0.284 0.003156	0.333 0.003697	0.383 0.004256	0.432 0.004797	0.480 0.005338	0.529 0.005878	0.579 0.006437	0.628 0.006978	0.677 0.007519	0.776 0.008618	0.873 0.009700
0.156					0.355 0.003939	0.405 0.004497	0.453 0.005038	0.502 0.005579	0.551 0.006120	0.601 0.006679	0.650 0.007220	0.698 0.007761	0.797 0.008860	0.895 0.009942
0.188						0.417 0.004747	0.476 0.005288	0.525 0.005829	0.573 0.006370	0.624 0.006928	0.672 0.007469	0.721 0.008010	0.820 0.009109	0.917 0.010191
0.250								0.568 0.006313	0.617 0.006853	0.667 0.007412	0.716 0.007953	0.764 0.008494	0.863 0.009593	0.961 0.010675

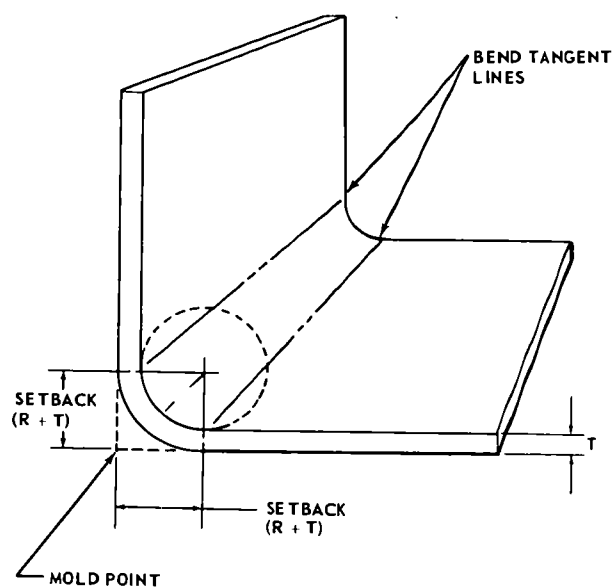


Figure 123. Setback, 90-degree bend.

Table 26. Setback, K-Chart

XXVI. -Chart

Angle (deg)	K-value	Angle (deg)	K-value
1	0.00873	21	0.18534
2	0.01745	22	0.19438
3	0.02618	23	0.20345
4	0.03492	24	0.21256
5	0.04366	25	0.22169
6	0.05241	26	0.23087
7	0.06116	27	0.24008
8	0.06993	28	0.24933
9	0.07870	29	0.25862
10	0.08749	30	0.26795
11	0.09629	31	0.27732
12	0.10510	32	0.28674
13	0.11393	33	0.29621
14	0.12278	34	0.30573
15	0.13165	35	0.31530
16	0.14054	36	0.32492
17	0.14945	37	0.33459
18	0.15838	38	0.34433
19	0.16734	39	0.35412
20	0.17633	40	0.36397

Angle (deg)	K-value	Angle (deg)	K-value
41	0.37388	95	1.0913
42	0.38386	96	1.1106
43	0.39391	97	1.1303
44	0.40403	98	1.1504
45	0.41421	99	1.1708
46	0.42447	100	1.1917
47	0.43481		
48	0.44523	101	1.2131
49	0.45573	102	1.2349
50	0.46631	103	1.2572
		104	1.2799
51	0.47697	105	1.3032
52	0.48773	106	1.3270
53	0.49858	107	1.3514
54	0.50952	108	1.3764
55	0.52057	109	1.4019
56	0.53171	110	1.4281
57	0.54295	111	1.4550
58	0.55431	112	1.4826
59	0.56577	113	1.5108
60	0.57735	114	1.5399
		115	1.5697
61	0.58904	116	1.6003
62	0.60086	117	1.6318
63	0.61280	118	1.6643
64	0.62487	119	1.6977
65	0.63707	120	1.7320
66	0.64941		
67	0.66188	121	1.7675
68	0.67451	122	1.8040
69	0.68728	123	1.8418
70	0.70021	124	1.8807
		125	1.9210
71	0.71329	126	1.9626
72	0.72654	127	2.0057
73	0.73996	128	2.0503
74	0.75355	129	2.0965
75	0.76733	130	2.1445
76	0.78128	131	2.1943
77	0.79543	132	2.2460
78	0.80978	133	2.2998
79	0.82434	134	2.3558
80	0.83910	135	2.4142
		136	2.4751
81	0.85408	137	2.5386
82	0.86929	138	2.6051
83	0.88472	139	2.6746
84	0.90040	140	2.7475
85	0.91633		
86	0.93251	141	2.8239
87	0.80978	142	2.9042
88	0.96569	143	2.9887
89	0.98270	144	3.0777
90	1.0000C	145	3.1716
		146	3.2708
91	1.0176	147	3.3759
92	1.0355	148	3.4874
93	1.0538	149	3.6059
94	1.0724	150	3.7320

Table 26. Setback, K-Chart—Continued

Angle (deg)	K-value	Angle (deg)	K-value
151	3.8667	166	8.1443
152	4.0108	167	8.7769
153	4.1653	168	9.5144
154	4.3315	169	10.385
155	4.5107	170	11.430
156	4.7046		
157	4.9151	171	12.706
158	5.1455	172	14.301
159	5.3995	173	16.350
160	5.6713	174	19.081
		175	22.904
161	5.9758	176	26.636
162	6.3137	177	38.138
163	6.6911	178	57.290
164	7.1154	179	114.590
165	7.5957	180	Infinite

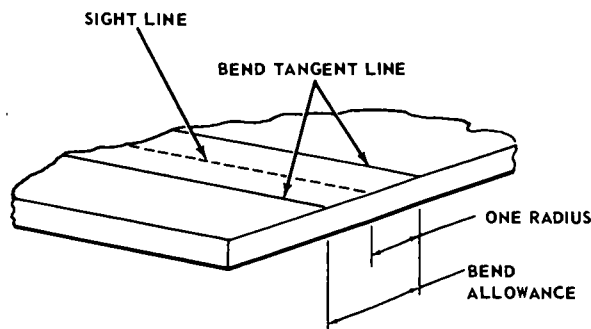
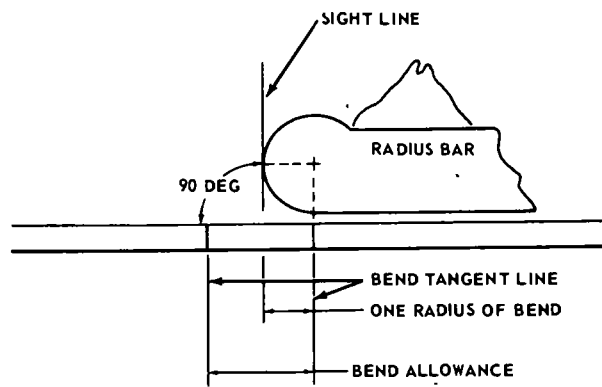


Figure 124. Brake or sight line.

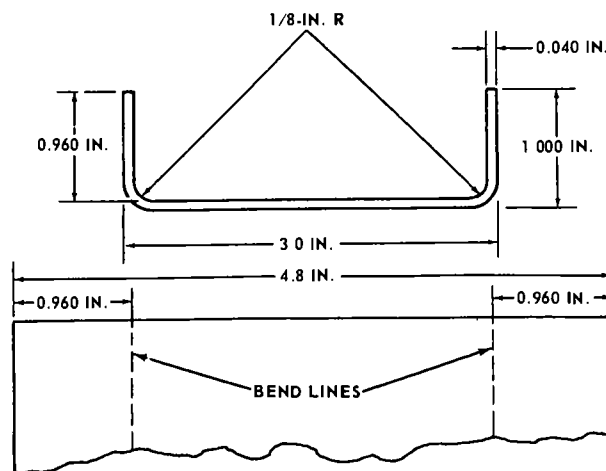


Figure 125. Example of simple flat layout method.

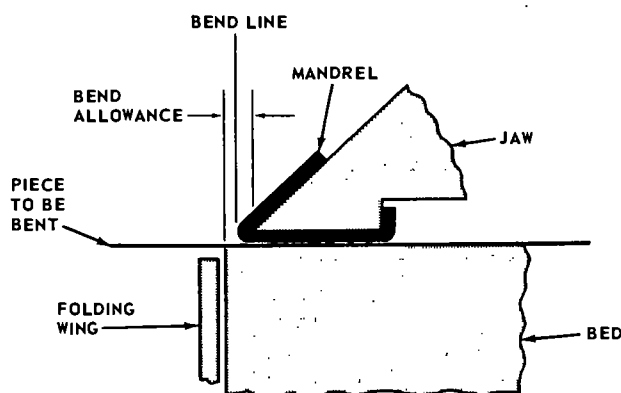


Figure 126. Locating bend line in the brake.

Section V. METHODS OF EVOLVING PATTERNS OR TEMPLATES

85. Flat Layout

The airframe repairman may have flat layout work to perform such as shown in figure 127. This problem involves laying out a flat pattern of a channel in which the left-hand flat, A, is to be 1 inch high, the right-hand flat, C, is to be 1 1/4 inches high, and the distance between the outside surface of the two flats, B area, is to be 2 inches. The material is 0.051 inch thick and the radius of bend is to be 3/16 (0.188) inch. The bend angles are to be 90°.

a. *Layout of First Flat.* First, determine the setback in order to establish the distance of the

flats. The setback for the first bend is $R + T$, or $0.188 + 0.051 = 0.239$ inch. The first flat A is equal to the overall dimension less the setback, or $1.000 - 0.239 = 0.761$ inch. Then find the bend allowance from table 25 for the first bend ($BA = 0.331$ in.). Now lay off these measurements as shown in figure 127 to determine the beginning and ending of each bend.

b. *Layout of Second Flat.* Lay out the second flat, B. This is equal to the overall dimension less the setback at each end, or $2.000 - (0.239 + 0.239) = 1.522$ inch (fig. 127). The bend allowance for the second bend is the same as that

for the first bend (0.331 in.). Mark off this distance as shown in figure 127.

c. *Layout of Third Flat.* The third flat, C, is equal to the overall dimension less the setback, or $1.250 - 0.239 = 1.011$ inch. Lay out this measurement as shown in figure 127.

d. *Calculate Measurements.* Adding the measurements of flats A, B, and C, and both bend allowances ($0.761 + 0.331 + 1.522 + 0.331 + 1.011$), the sum is 3.956, or approximately 4.0 inches. Totaling the three flats, A, B, C, 1 inch, 2 inches, and $1\frac{1}{4}$ inches, respectively, the sum is 4.250 inches of material length. Notice how setback and bend allowance affect material lengths in forming straight line bends. In this case the reduction is approximately $\frac{1}{4}$ -inch. If the angles were not right angles, the setback values can be taken from the K-chart, table 26.

e. *Cut Out and Bend Material.* After all measurements are calculated, cut the material and mark off the brake or sight lines as shown in figure 127 and use the brake to form the channel.

86. Pattern Developments

The airframe repairman will have work which will involve repairs to ducts and pipes. In some cases these items may have to be designed to fit other ducts or pipes at various angles, such as a round air duct joining a square one. By mathematical calculations and drafting methods, the airframe repairman will have to determine the

size, shape, and curve of the cuts, which when laid out on a flat pattern or blank piece of sheet stock, formed, and put together, will give the correct shape of the object. The edge of the round duct that attaches to the square duct is not a straight line when drawn on a flat sheet, but is a flowing curve. It ascends gradually to a peak, and then descends gradually on the opposite side. Should the blank be cut out along this curved line and rolled up, it would fit snugly against the elliptical hold in the square duct. The airframe repairman makes such sketches on paper first, then cuts out and fits the patterns together before using them on the sheet stock. The process by which the airframe repairman projects and drafts lines and curves into layouts is called development. Such airframe drafting is based on those principles of geometry which relate to the surface of solids. Sheet metal articles are hollow and, in airframe drafting, they are considered as if they were coverings for solids of the same shapes. The three commonly used methods of development are parallel line development, radial line development, and triangulation. These three methods can be used to develop objects with single curvatures only. Articles such as wing fillets and cowlings parts have compound curvatures, that is, bulges which curve in at least two directions at the same time and require stretching and shrinking. They are undevelopable; with size and form determined by trial and error or by slitting the old part open and flattening it out.

a. *Parallel Line Development.* Parallel line development is applicable to forms such as pipes, ducts, T-joints, and the like, which have opposite sides parallel. When laying out patterns for a cylindrical object, consider the object as a form having an infinite number of sides, each of the same length as the form but very narrow. During this process of development, first draw an elevation view to show the true length of the sides of the object; next, draw a plan view or a half plan view to show the true size and shape of the end of the object (fig. 128). Strike off equal distances along the curved line of the half plan, dividing the area around the cylinder into equal parts. (The greater the numbers of parts, the more nearly accurate the layout.) Now draw a stretchout line. This is drawn from the base of the elevation view (fig. 128). On this line, locate the number of equal spaces laid out on the half plan view. Keep in mind that the other half of the cylinder will have to be formed to, so locate and number the spaces in the pattern from 1 up to 7 then back to 1 again (fig. 128). Through these points, draw measuring lines at right angles to the stretchout line. Also, from the points

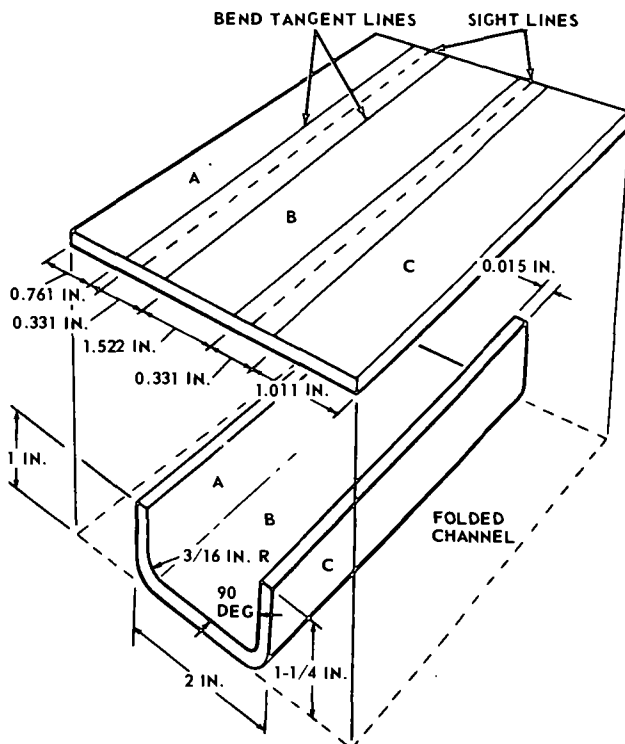


Figure 127. Flat layout of a channel.

2 to 6 laid out in the half plan, draw lines to the top line in the elevation view. Draw all these lines perpendicular to the base line. Next, draw projection lines parallel to the stretchout line and through the points where the vertical lines from the half plan view intersect the top line of the elevation view. Mark the points where these projection lines intersect the correspondingly numbered measuring lines; then connect all these points with an easy-flowing curved line. This curve forms the top angular edge of the pattern. The stretchout line forms the base of the object.

b. *Radial Line Development.* Several objects have shapes which will not permit the use of parallel line development because their sides are not parallel. Such forms require other methods of development. Radial line development is one such method; and, as in parallel line development, the objects to be developed must have certain characteristics. Only forms which have a circle for their bases, or a base that can be inscribed in a circle, and sides that slant to a common center, can be developed by this method. The center must be located directly over the center of the base. This base, however, may be projected or imaginary rather than the actual base of the object. When the base is round, the object has a

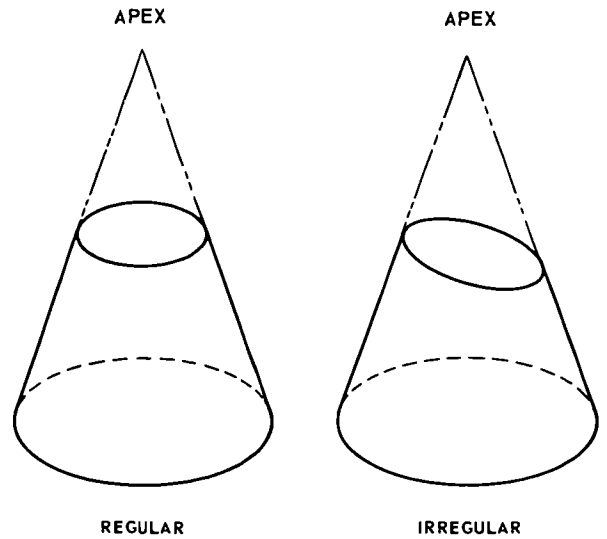


Figure 130. Truncated cones.

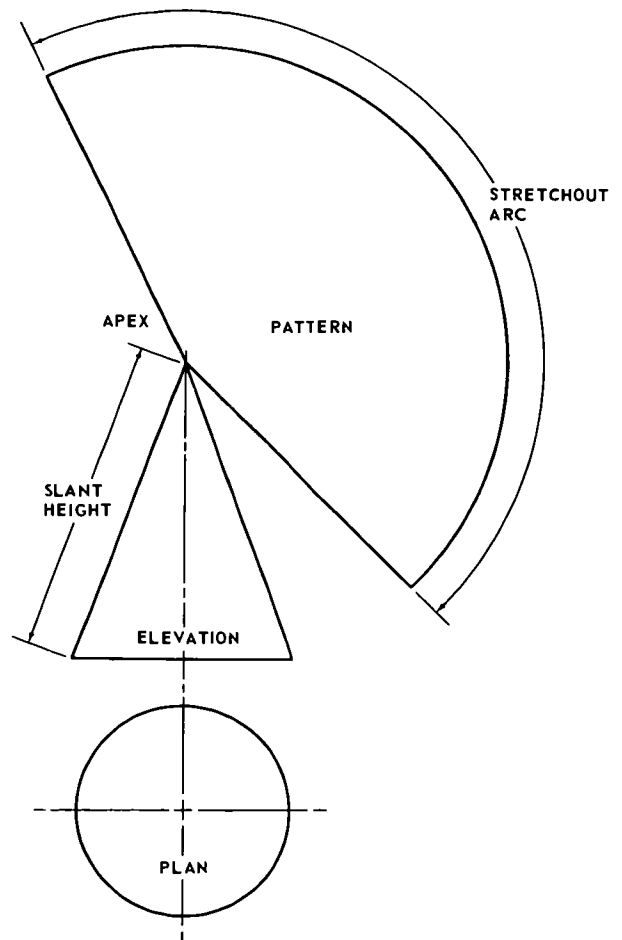


Figure 131. Cone stretchout.

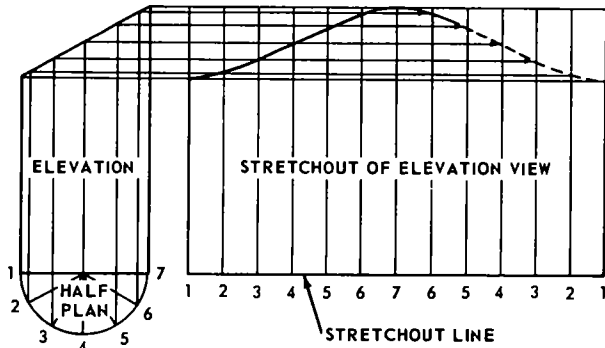


Figure 128. Parallel line development.

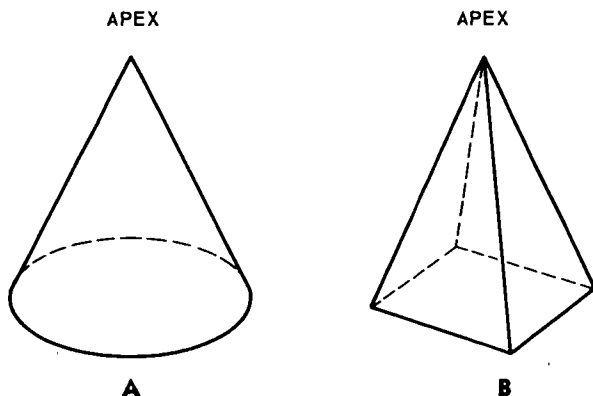


Figure 129. Objects developed by radial line method.

conical shape as shown in figure 129, example A. When the object has a square base, it has the shape of a pyramid as shown in example B. Any part or section of these cones or pyramids can be developed by radial line development.

(1) A cone with the top cut off parallel with the base as shown in figure 130 is called a regular frustum. One with the top cut off on an angle with the base is called an irregular frustum. Objects which have these characteristics can be developed by the radial line method. When drawing a frustum, the apex is located by extending the sides until they intersect. This point of intersection of imaginary lines is the apex. The apex must be located, regardless of the shape, in order to obtain the slant height.

Generally, the pattern of these objects is fan-shaped. When the object is unrolled, the stretchout pivots around the apex or the pattern radiates from the apex as shown in figure 131. The pattern for a cone is found by using the elevation view and plan view. In this type of line development the elevation has two heights, the actual and the slant. The actual height is used only to draw the elevation view, and the slant height is used as the radius for the stretchout arc. The length of the stretchout arc is equal to the distance around the base or plan view. The slant height is the distance from the apex to the base down the visible slant. Note in figure 132 the pattern of an object whose base is not round. However, the radius and the length of the stretchout arc are found in the same manner as if the base of the object were round.

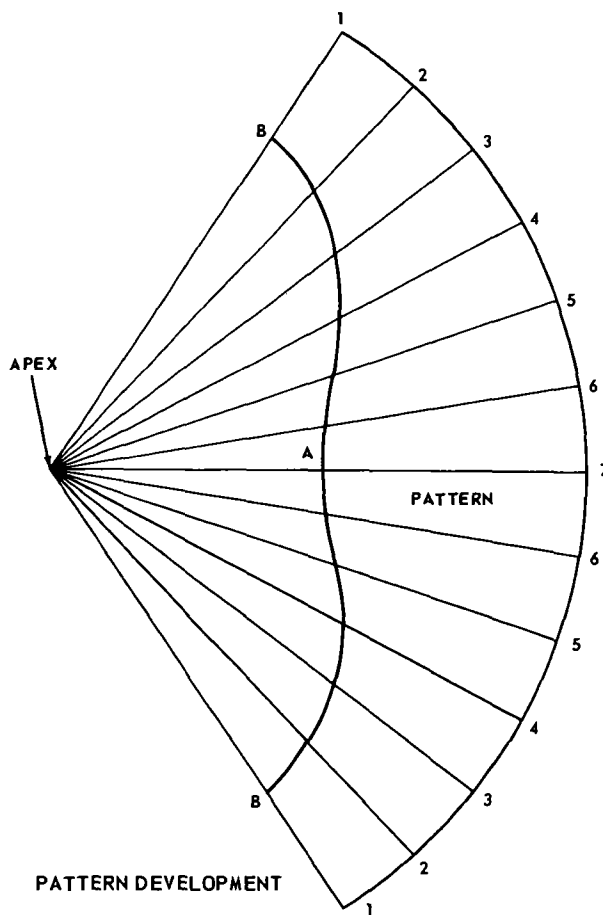
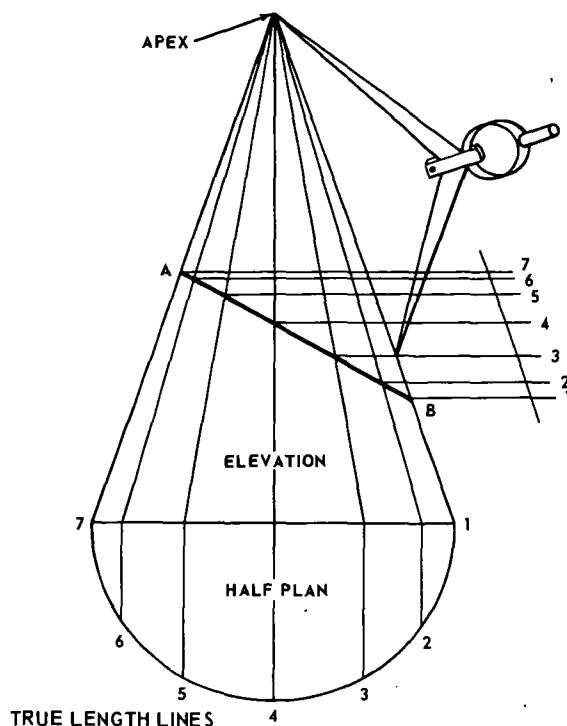


Figure 133. Irregular frustum development.

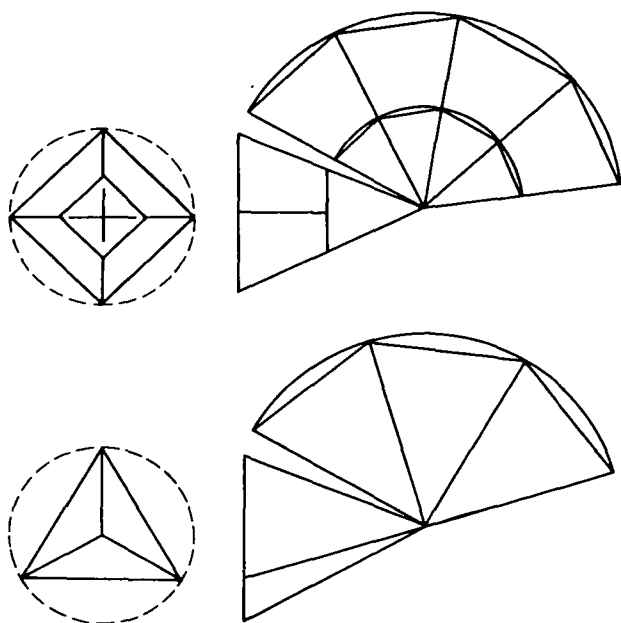


Figure 132. Patterns for objects without round bases.

(2) An irregular frustum presents a slightly different situation, the difference being that the pattern line A-B shown in figure 133 could not be shown as an arc. Therefore, to pinpoint it on the pattern, surface element lines must be constructed on the elevation view. The plan, or half plan, is divided into equal spaces and then extended up perpendicular to the base line. From there, all surface element lines converge to one point, the apex.

(3) In parallel line development, the surface element lines are perpendicular to the base; but, in radial line development, they are not perpendicular to the base line. These lines are on a slant and therefore are shortened. The only lines that are in their true length are the slant height lines. In order to find the true length of all surface lines, simply project them from line A-B (miter line) to the slant height as shown in figure 133. All true lengths are taken along the slant height side. To develop the pattern shown in figure 133, swing the stretchout arc using the slant height as the radius. After the length of the arc has been determined by measuring the distance around the base of the object, divide the arc into surface element lines corresponding to those in the elevation view and transfer the measurement to the lines having the same number as in the pattern. After locating all points, connect them with a curved line to form the outline of the pattern. The steps in developing a pattern using the radial line method are—

(a) *Layout of half plan view.* Swing half circle equal to the diameter of the base. Divide half plan view into equal parts with dividers. Extend surface lines upward to base line.

(b) *Layout of elevation view.* Draw the elevation view. Extend sides up centerline to obtain the apex. Extend all surface element lines from base line to the apex (top). Construct true lengths if the object is an irregular frustum. (If the object is a regular frustum or cone, no true lengths are necessary; the slant height is then used.) The true lengths are constructed by projecting lines parallel to base line from the points of intersection of the surface element lines and the miter line over to the slant height. Letter and number all points of importance on the layout.

(c) *Layout of pattern.* Take the distance along the slant height from the apex to the base line and swing the stretchout arc. Set dividers to the equal space between surface element lines on circumference of half plan view. Mark off equal spaces on the length of the stretchout arc.

Extend the surface element lines from the stretchout arc to the apex. Transfer the true lengths of the surface element lines from the elevation view to pattern, measuring from the apex down the slant height to the numbered true length lines drawn out from the miter line. (If the object is a regular frustum or cone, no true lengths are needed.) Draw curve and add seam allowance to the ends of pattern.

c. *Triangulation.* The process of triangulation is used for the layout of irregular forms having sides which are not parallel and which, if extended, would not meet at a common point (fig. 134). Forms of this type cannot be developed by methods other than triangulation. Triangulation is applicable to a wide range of layout problems and, though more detailed than other methods, it is simple and easy to use when the underlying principles are understood. Procedures for the development of a pattern are outlined below (fig. 134).

- (1) Draw the elevation view of the object (fig. 134).
- (2) Draw the plan view of the object.
- (3) Divide the circle in the plan view into

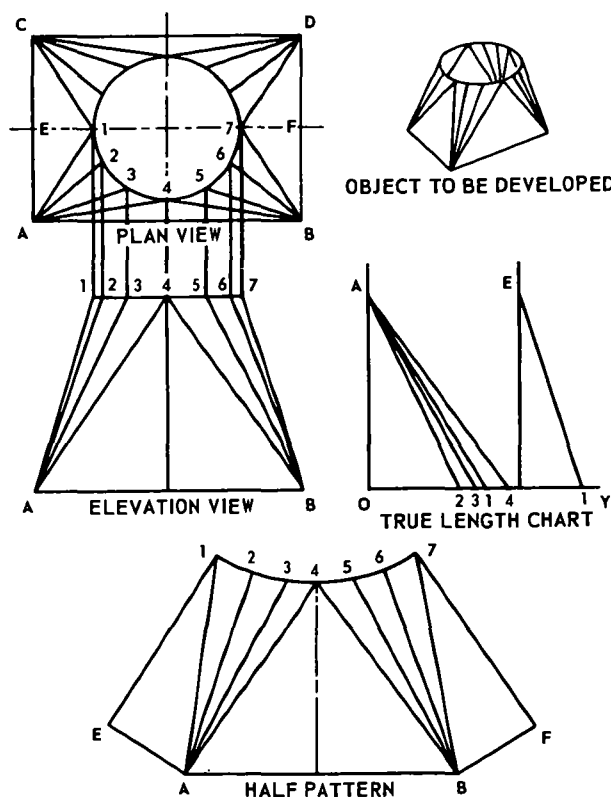


Figure 134. Development by triangulation.

a convenient number of parts. Number each point.

(4) Draw lines to each of the corners A, B, C, and D.

Note. Since lines A-1, A-2, A-3, and so on are fore-shortened lines, it is necessary to determine their true length before they can be used in the layout of the pattern. This can be accomplished by the use of a true length chart constructed as described in (5) below.

(5) Construct a true length chart by first drawing line AO perpendicular to a base line OY. Transfer the distance of lines A-1, A-2, A-3, and A-4 in the plan view to the base line OY. Each distance must begin at point O. Now draw lines to these points from point A, thus producing the true length of the lines. (Since this object is symmetrical, the following combinations of lines are the same length: A-4 and B-4, A-3 and B-5, A-2 and B-6, A-1 and B-7.)

(6) Lay out the half pattern as follows:

(a) Lay out base line AB

(b) Locate point 4 by scribing arcs using radii equal to true length of lines A-4 and B-4. Draw line A-4 and B-4 on the pattern.

(c) Set dividers to length 3-4 on the plan view. Using this measurement, scribe arcs to the right and left of point 4 on the pattern.

(d) From pattern points A and B, respectively, scribe arcs having radii equal to the true length of lines A-3 and B-5 to intersect the previously made arcs. Draw lines A-3 and B-5.

(e) Continue laying out the pattern, locating points 2, 1, 6, and 7 by using the same procedures as were used to locate points 3, 4, and 5.

(f) Construct triangles A-E-1 and B-F-7 of the pattern by scribing arcs from points A and B using a radius equal to the true length of line AE, and scribing arcs from points 1 and 7 using a radius equal to the true length of line E-1. Draw lines through the points of intersection for these arcs.

Note. These procedures will develop only one-half pattern for the object. The other half pattern can be developed by repeating these procedures or by reversing this pattern when cutting the sheet stock for manufacture of the object. Extra material must be added for the seam to be used. Where the object is unsymmetrical (not uniform), the remaining sides also have to be laid out, using a separate true length chart.

87. Duplication of Pattern

The airframe repairman may have to duplicate parts without the aid of blueprints. This will

require taking measurements directly from the original or from a duplicate part. In studying the following instructions for laying out a part to be duplicated, refer to figure 135.

a. Pattern Duplication Layout.

(1) Draw a reference (datum) line, AB, on the sample part and a corresponding line on the template material as shown in example 1, figure 135.

(2) With point A on the sample part as a center, draw an arc having a radius of approximately 1/2 inch and extending to the flanges as shown in example 2, figure 135.

(3) Draw similar arcs each with a radius 1/2 inch greater than the previous one until the entire part has been marked. In case there is an extremely sharp curve in the object, decrease the distance between the arcs to increase the number of arcs. This procedure will increase the accuracy of the layout. An arc must pass through every corner of the part; one arc may pass through more than one corner as shown in example 3, figure 135.

(4) Locate the coordinate point on the layout by measuring on the part with dividers. Always measure the distance from the reference point to the beginning of the bend line on the flange of the part.

(5) After locating all similar points, draw a line through them, using a French curve to insure a smooth pattern. See example 4, figure 135.

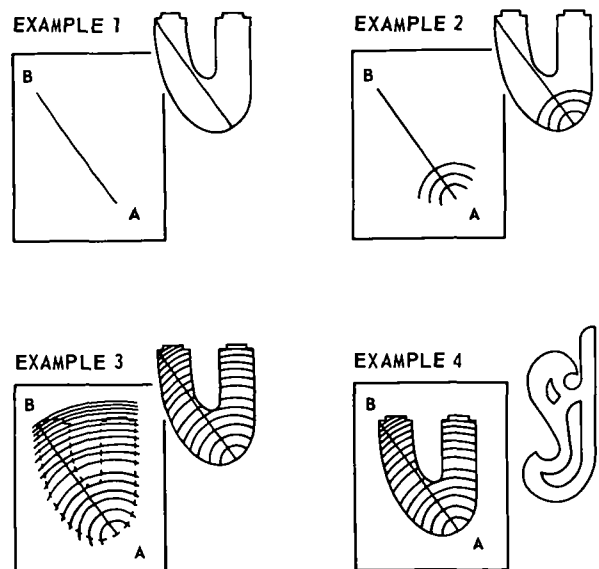


Figure 135. Duplicating a pattern.

(6) Allow for additional material for forming the flange and locate the inside bend tangent line by measuring, inside of the sight line, a distance equal to the radius of bend of the part. Using the intersection of the lines as a center, locate the required relief holes. Then cut out and form as necessary.

b. Relief Holes. Where two bends intersect, material must be removed to make room for the material contained in the flanges. Holes are therefore drilled at the intersection. These holes, called relief holes, as shown in figure 136, prevent strains from being set up at the intersection of the inside bend tangent lines. Such strains may cause the metal to crack. Relief holes also provide a neatly trimmed corner where the excess material is trimmed away. The size of relief holes varies with thickness of the material. They should not be less than 1/8 inch in diameter for aluminum alloy sheet stock up to and including 0.064 inch thick, or 3/16 inch for stock ranging in thickness from 0.072 inch to 0.128 inch. The most common method of determining the diameter of a relief hole is to use the radius of bend for this dimension, provided it is not less than the minimum allowance (1/8 inch). It is good practice to use the intersection of these lines as the center for the holes (fig. 136). The line on the inside of the curve is cut at an angle toward the relief holes to allow for the stretching of the inside flange.

c. Lightening Holes.

(1) Occasionally, holes are cut in rib sections, fuselage frames, and other structural parts to decrease weight. Such holes are known as lightening holes. To keep from weakening the member (by removal of the material), flanges are often pressed around the holes to strengthen the area from which the material was removed. These holes should never be cut in any structural part unless authorized. The size of the lightening hole and the width of the flange formed around the hole are determined by design specifications. Margins of safety are considered in the specifications so that the weight of the part can be decreased and still retain the necessary strength. These lightening holes are cut by any of the following methods:

(a) Punching out, if the correct size punch die is available.

(b) Cutting out with a fly-cutter mounted on a drill.

(c) Scribing circumference of a hole with dividers and drilling around the entire circum-

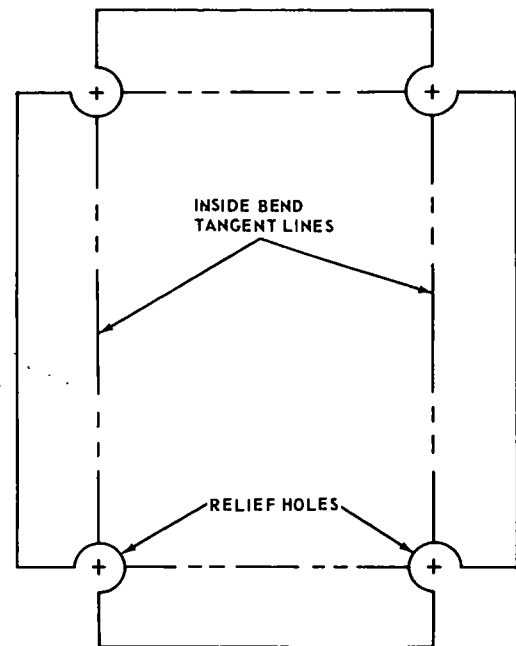
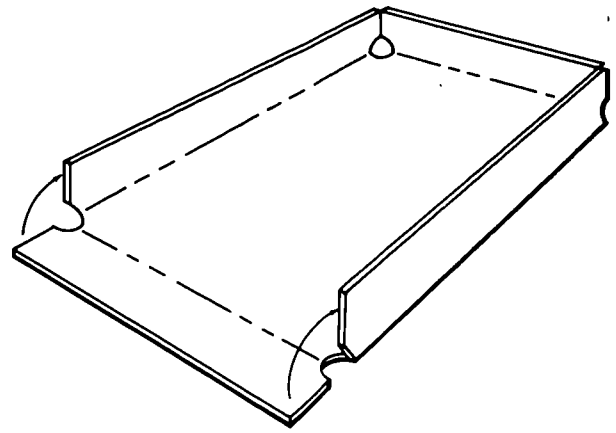


Figure 136. Locating relief holes.

ference with a small drill, allowing enough clearance to file smooth.

(d) Scribing the circumference of the hole with dividers, drilling the hole inside the circumference large enough to insert snips, cutting out excess metal, and filing smooth.

(2) Form the flange by using a flanging die, or hardwood or metal form blocks. Flanging dies consist of two matching parts, a female and a male die. For flanging soft metal, dies can be of hardwood, such as maple. For hard metal or for more permanent use, they should be made of steel. The pilot guide should be the same size as the hole to be flanged, and the shoulder should be the same width and angle as the desired flange. When flanging lightening holes, place the material between the mating parts of the die and form it by hammering or squeezing the dies together

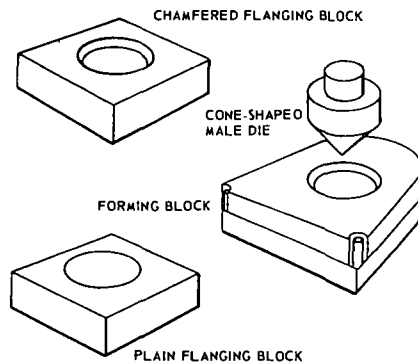


Figure 137. Flanging form blocks.

Section VI. HAND-FORMING OF ALUMINUM

88. General

All forming revolves around the process of shrinking and stretching, and hand-forming processes are no exception. If a formed or extruded angle is to be curved, one leg may be stretched or the other shrunk, whichever will make the part fit the job. In bumping, the material in the bulge is stretched to make it balloon, and in joggling, the material between the joggles is stretched. Material in the edge of lightening holes is often stretched to form a beveled reinforcing ridge around them.

89. Straight Line Bends

The cornice brake and bar folder are ordinarily used to make straight bends. However, these machines may not always be available and the airframe repairman should know how to hand-form folds or bends. This can be accomplished with the aid of wooden or metal bending blocks.

a. Layout. Lay out the material as required and cut the blank piece out. Clamp the material rigidly along the bend line between 2 wooden form blocks. Position and hold this arrangement in a vise. The wooden forming block should have one edge rounded as necessary for the desired radius of bend. It should also be curved slightly beyond the 90-degree point to allow for springback.

b. Work. With the sheet held firmly in the vise by the form blocks, use a rubber, plastic, or rawhide mallet and lightly rap the metal sheet. This will start the metal protruding beyond the bending blocks to the desired angle. Start tapping at one end and work back and forth along the edge, making the bend gradually

in a vise or in an arbor press. The dies will work more smoothly if they are coated with light machine oil.

(3) In the two form blocks shown in figure 137, the hole in the chamfered flanging block is the same size as the hole to be flanged and is chamfered to the width of the flange and the angle desired, while in the forming block, the hole is the same diameter as that of the flange. Either type may be used. When using the chamfered flanging block, center the material to be flanged and hammer it with a stretching mallet, around and around, until the flange conforms to the chamfer.

and evenly. Continue this process until the protruding metal is forced down to the desired angle against the forming block. Allow for springback by driving the material slightly farther than the actual bend. If a large amount of metal extends beyond the bending blocks, maintain hand pressure against the protruding sheet to prevent bouncing. Remove any irregularities by holding a straight block of hardwood edge-wise against the bend and striking it with heavy blows of a mallet or hammer. If the amount of metal protruding beyond the bending block is small, make the entire bend by using the hardwood block and hammer.

90. Curving Formed or Extruded Angles

Both formed and extruded types of angles can be curved (not bent sharply) by stretching or shrinking either of the flanges. Curving by stretching one flange is usually preferred since this process requires only a V-block and a mallet and is very easily accomplished (fig. 119).

a. Stretching One Flange.

(1) Position the flange to be stretched in the groove of the V-block. Using a stretching mallet, strike the flange directly over the V portion with light, even blows and gradually force it downward into the V. (Too heavy a blow will buckle the angle strip.) Keep moving the angle strip across the V-block while continuing to lightly strike the spot directly above the V. Form the curve gradually and evenly as the strip is moved slowly back and forth, distributing the hammer blows at equal spaces on the flange.

(2) Lay out a full-sized, accurate pattern on a sheet of paper or plywood and periodically check the accuracy of the curve. It is better to

get the curve to conform roughly to the desired shape before attempting to finish any one portion, because the finishing or smoothing of the angle may cause some other portion of the angle to change shape. If any part of the angle strip is curved too much, reduce the curve by reversing the angle strip on the V-block, placing the bottom flange up, and striking it light blows with the mallet.

(3) Try to form the curve with a minimum amount of hammering, for excessive hammering will work-harden the metal. Work-hardening can be recognized by a lack of bending response or by springiness in the metal. It can be recognized very readily by an experienced worker. In some cases, the part may require annealing during the curving operation. If so, be sure to heat-treat the part again before installing it on the aircraft.

b. Shrinking One Flange. Curving an extruded or formed angle strip by shrinking may be accomplished by either of two methods, the V-block method or the shrinking block method. Of the two, the V-block is, in general, more satisfactory because it is faster, easier, and affects the metal less. However, very good results can be obtained by the shrinking block method.

(1) V-block shrinking method can be accomplished by positioning one flange of the angle strip flat on the V-block with the other flange extending upward, as shown in figure 119. Hold it firmly so that it does not bounce when hammered, and strike the edge of the upper flange with light blows of a round, soft-faced mallet. Begin at one end of the angle strip and, working back and forth, strike light blows directly over the V-portion of the block. Strike the edge of the flange at a slight angle as this tends to keep the vertical flange from bending outward. Occasionally, check the curve for accuracy with pattern. If a sharp curve is made, the angle (cross section of the formed angle) will close slightly. To avoid such closing of the angle, clamp the angle strip to hardwood board with the hammered flange facing upward. Use small C-clamps on which the jaws have been covered with masking tape. If the angle has already closed, the flange can be brought back to the correct angle with a few blows of a mallet or with the aid of a small hardwood block. If any portion of the angle strip is curved too much, reduce it by reversing the angle on the V-block and hammering with a suitable mallet, as explained in *a* above. When the proper curve has been made, smooth the entire angle by planishing with a soft-faced mallet.

(2) The shrinking block method is used when the angle form is to be quite sharp. In this process, crimp the flange which is to form the inside of the curve. When making a crimp, hold the crimping pliers so that the jaws are about 1/8 inch apart. By rotating the wrist back and forth, bring the upper jaw of the pliers into contact with the flange, first on one side and then on the other side of the lower jaw. Complete the crimp by working a raised portion into the flange, gradually increasing the twisting motion of the pliers. Do not make the crimp too large as it will be difficult to work out. The size of the crimp depends upon the thickness and softness of the material, but usually about 1/4 inch is sufficient. Place several crimps spaced evenly along the desired curve with enough space left between each crimp so that jaws of the shrinking block can easily be attached. After completing the crimping, place the crimped flange in the shrinking block so that one crimp at a time is located between the jaws. Flatten each crimp with light blows of soft-faced mallet, starting at the apex (the closed end) of the crimp and gradually working toward the edge of the flange. Check the curve of the angle with a pattern periodically during the forming process and again after all the crimps have been worked out. If it is necessary to increase the curve, add more crimps and repeat the process. Space the additional crimps between the original ones so that the metal will not become unduly work-hardened at any one point. If the curve needs to be increased or decreased slightly at any point, use the V-block. After obtaining the desired curve, it may be necessary to planish the angle strip over a stake or wooden form.

91. Forming Flanged Angles

The forming process for flanged angles is slightly more complicated than forming formed or extruded angles in that the bend is shorter (not gradually curved) and necessitates shrinking or stretching in a small or concentrated area. If the flange is to point toward the inside of the bend, the material must be shrunk. If it is to point toward the outside, it must be stretched.

a. Forming By Shrinking. In forming a flanged angle by shrinking, use wooden forming blocks similar to those shown in figure 138 and proceed as follows:

(1) Cut the metal to size, allowing for trimming after forming. Determine bend allowance for a 90-degree bend and round the edge of the forming block accordingly.

(2) Clamp the material in the form blocks as shown in figure 138, and bend the exposed flange against the block. After bending, tap the blocks slightly. This induces a setting process in the bend.

(3) Using a soft-faced shrinking mallet, start hammering near the center and work the flange down gradually toward both ends. The flange will tend to buckle at the bend because the material is made to occupy less space. Work the material into several small buckles instead of one large one, and work each buckle out gradually by hammering lightly and gradually compressing the material in each buckle. The use of a small hardwood wedge block as shown in figure 138, will aid in working out the buckles.

(4) Planish the flange after it is flattened against the form block, and remove small irregularities. If the form blocks are made of hardwood, use a metal planishing hammer; if the forms are made of metal, use a soft-faced mallet. Trim the excess material away and file and polish.

b. Forming By Stretching. To form a flanged angle by stretching, use the same forming blocks, wooden wedge block, and mallet as in the shrinking process. Proceed as follows:

(1) Cut the material to size (allowing for trim), determine bend allowance for a 90-degree bend, and round off the edge of the block to conform to the desired radius of bend.

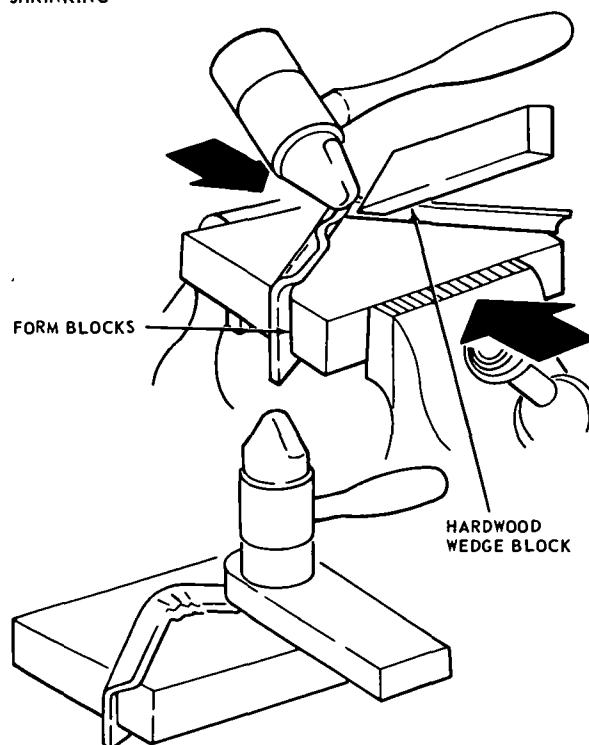
(2) Clamp the material in the form blocks as shown in figure 138.

(3) Using a soft-faced stretching mallet, start hammering near the ends and work the flange down smoothly and gradually to prevent cracking and splitting. Planish the flange and angle described in *a*(4) above and trim and smooth the edges, if necessary.

92. Forming Curved Flanged Parts

Curved flanged parts are usually hand-formed. Of the types shown in figure 138, the rib with relief holes is probably the simplest to form. It has a concave flange (the inside flange) and a convex flange (the outside flange). The concave flange is formed by stretching; the convex flange by shrinking. Such parts may be formed with the aid of hardwood or metal forming blocks. These blocks are made in pairs similar to those used for straight angle bends and are identified in the same manner. They differ in that they are made specifically for the particular part to

SHRINKING



STRETCHING

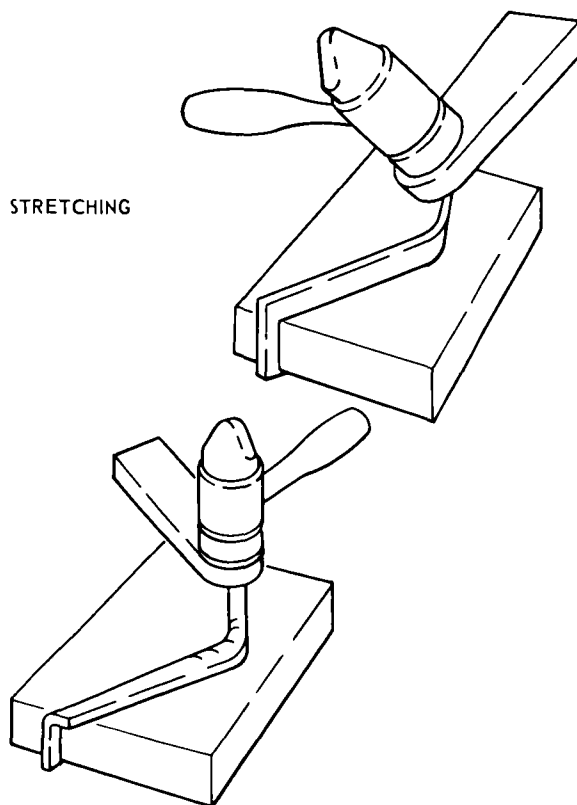


Figure 138. Forming a flanged angle.

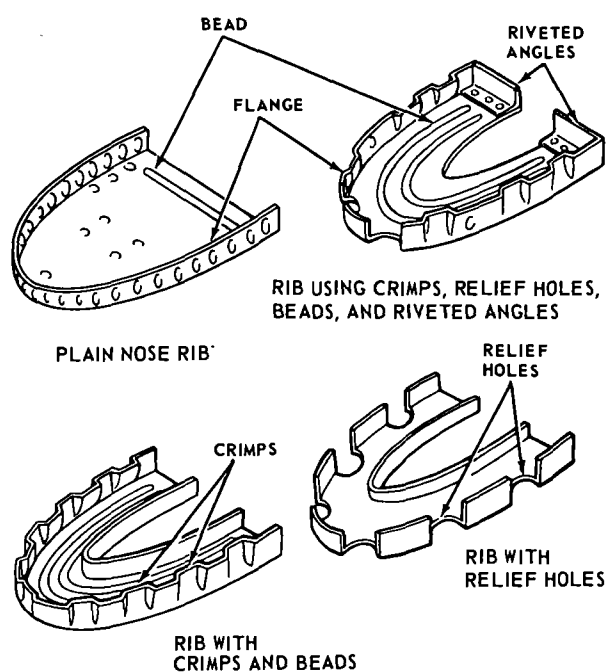


Figure 139. Nose ribs.

be formed, they fit each other exactly, and they conform to the actual dimensions and contour of the finished article. The mating parts may be equipped with aligning pins to aid in lining up the blocks and holding the metal in place. The blocks may be held together by C-clamps or a vise. They also may be held together with bolts by drilling through both forms and the metal, provided the holes do not affect the strength of the finished part. The edges of the forming block are rounded to give the correct radius of bend to the part, and are undercut to allow for springback of the metal. The undercut is especially necessary if the material is hard or if the bend must be highly accurate. Note the various types of forming represented in figure 139. In the plain nose rib, only one large convex flange is used; but, because of the great distance around the part and the likelihood of buckles in forming, it is rather difficult to form. The flange and the beaded portion of this rib provide sufficient strength to make this a very good type to use. In the type with relief holes, the concave flange gives difficulty in forming; however, the outside flange is broken up into smaller sections by relief holes (notches inserted to prevent strains in a bend). In the type with crimps and beads, note that crimps are inserted at equally spaced intervals. The crimps are placed to absorb material and cause curving, while also giving strength to the part. In the fourth nose

rib illustrated, note that a combination of the four common forming methods are applied. They are crimping, bending, putting in relief holes, and using a formed angle riveted on at each end. The beads and the formed angles supply strength for the part. In forming a curved flanged part, the major steps are outlined in the following subparagraphs.

a. Cut and Lay Out Material. Cut the material to size (allowing for trim), locate and drill holes for alignment pins, and remove all burrs (jagged edges). Place the material between the wooden blocks. Clamp blocks tightly in a vise so that the material will not move or shift. Clamp the work as closely as possible to the particular area being hammered to prevent strain on the form blocks and to keep the metal from slipping.

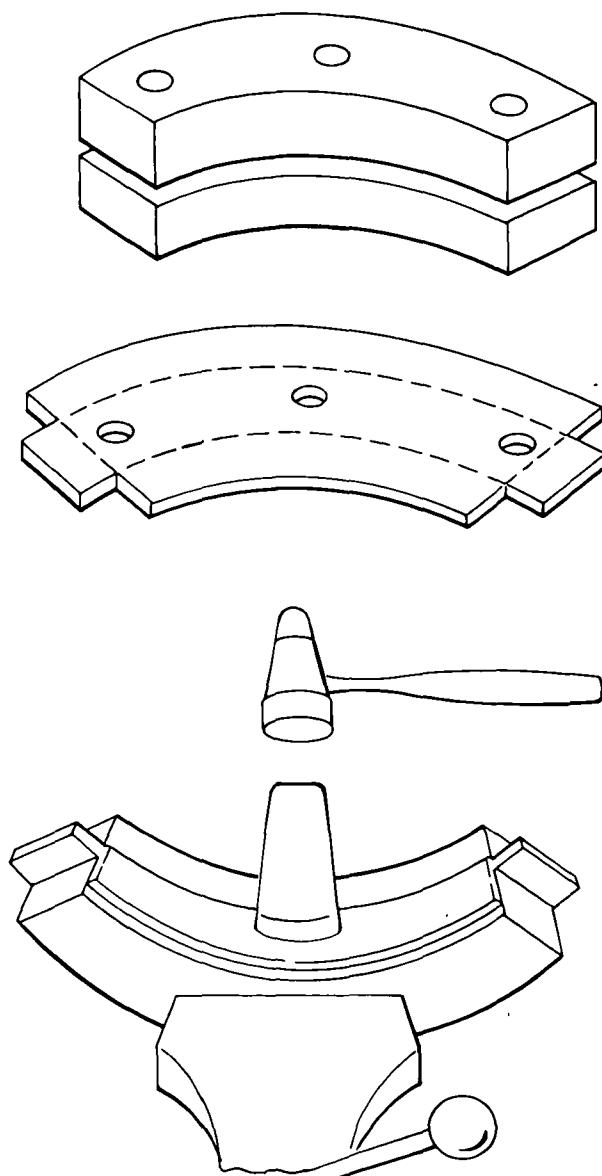


Figure 140. Forming a concave curve.

b. Forming Concave Flange Curve. Bend the flange on the concave curve first. The stretching process is more likely to cause the metal to split or crack than the shrinking process. (Should this occur, a new piece will have to be made.) Using a soft-faced mallet or wooden wedge block, start hammering at a point a short distance away from the beginning of the concave bend and continue toward the center of the bend. This procedure permits some of the excess metal along the tapered portion of the flange to be worked into the curve where it will be needed. Continue hammering until the metal is gradually worked down over the entire flange, flush with the form block (fig. 140).

c. Forming Convex Flange Curve. Starting at the center of the curve and working toward both ends, hammer the convex flange down over the form (fig. 141). Strike the metal with glancing blows, at an angle of approximately 30° off perpendicular, and with a motion that will tend to pull the part away from the block. Stretch the metal around the radius bend and remove the buckles gradually by hammering on a wedge block. While working the metal down over the form, keep the edges of the flange as nearly perpendicular to the block as possible. The wedge block helps keep the edge of the metal perpendicular to the block, lessens the possibility of buckles and of splitting or cracking the metal, and aids in removing buckles. Finally, trim the flanges of excess metal, planish, remove burs, round the corners (if any), and check the part for accuracy.

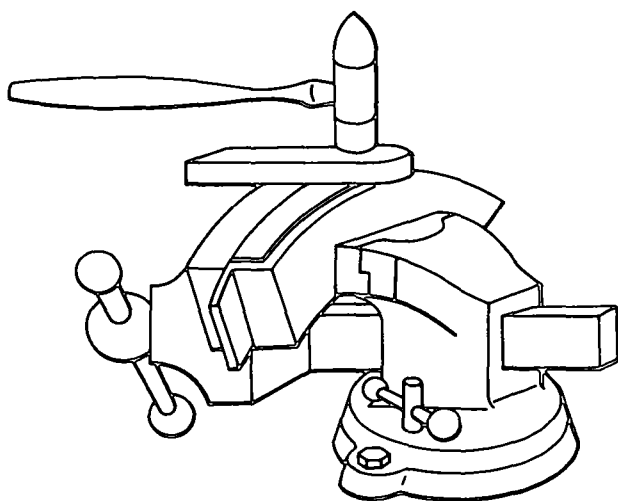


Figure 141. Forming a convex curve.

93. Bumping

Bumping on a form block or female die and bumping on a sandbag are the two common types practiced. In either method only one form is required, a wooden block, lead die, or sandbag. An example of a part made by the block or die type of bumping is the blister, or streamlined cover plate. Wing fillets constitute an example of parts that are usually formed by bumping on a sandbag.

a. Form Block Bumping. This process is accomplished by using a wooden block or lead die. The lead die or the wooden block designed for bumping must have the same dimensions and contour as the outside of the blister. To provide sufficient bucking weight, and to give sufficient bearing surface for fastening the metal, the block or die should be at least 1 inch larger in all dimensions than the form requires.

(1) When forming the wooden block, hollow it out with saws, chisels, gouges, files, and rasps. Smooth and finish it with sandpaper. Make the inside of the form as smooth as possible, because any slight irregularity will show up on the finished part. Prepare several templates (patterns of the cross section), such as those shown with the form block for the blister in figure 142, so that the form can be checked for accuracy.

(2) Shape the contour of the form at points 2, 3, and 4. Shape the areas between the template check points to conform to the remaining contour and to template 4. Shaping of the form block requires particular care because the more nearly accurate it is in all details, the less time it will take to produce a smooth, finished part.

(3) Correct clamping of the material to the form block is an important part of the block forming operation. Several methods are possible. For parts such as the blister, one of the best means of clamping the material is to use a full metal cutout or steel holddown plate as shown in figure 142.

(4) In this process, place the holddown plate directly over the material to be formed and clamp it in position with bolts or C-clamps. Tighten the C-clamps or bolts just tight enough to hold the material flat against the face of the form block, but not so tight that the metal cannot be drawn into the form. If the material is not held flat against the face of the form, it will bend up or buckle away from the block. If it is not permitted to slip into the concave depression a little, the blister portion will become very thin in places.

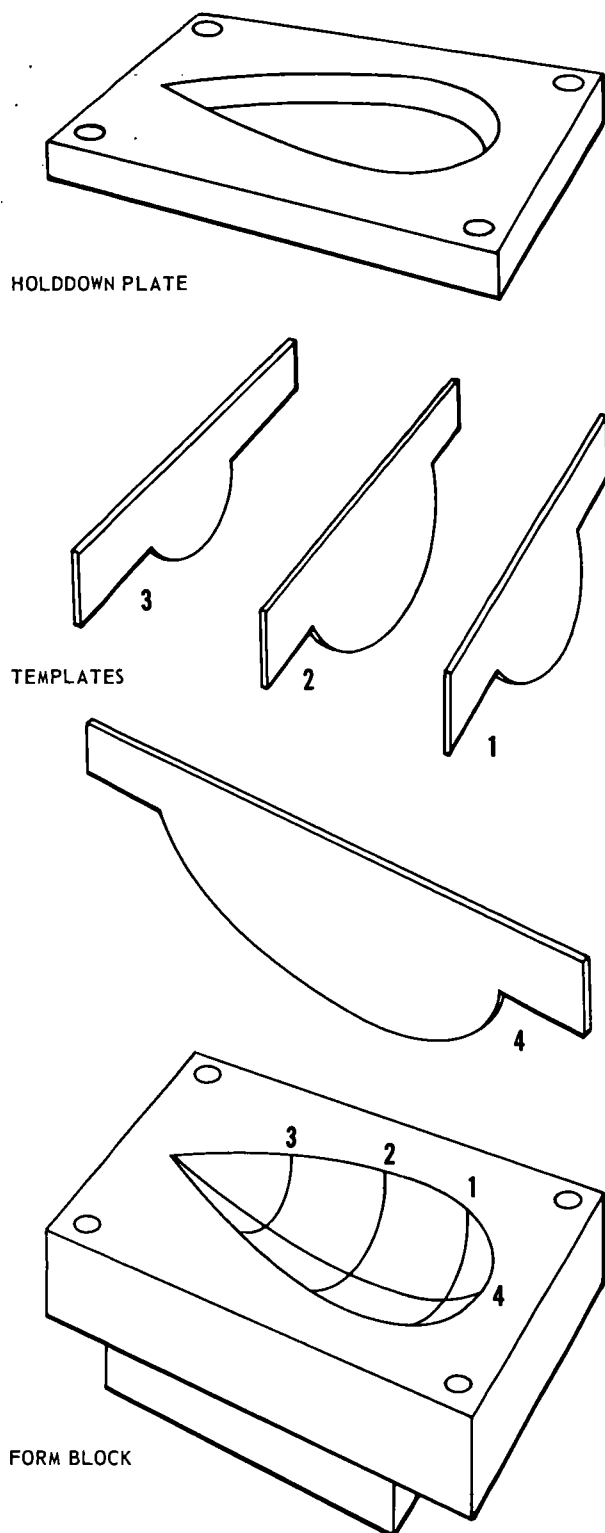


Figure 142. Form blocks and templates.

(5) Holddown plates should be of heavy steel, 1/8 inch for small forms and 1/4 inch or heavier for large forms. If the material for making a full metal holddown plate is not available, use a hardwood cutout. Make the cutout and use it in the same manner as the steel plate, but take greater precautions to make sure the material is held as desired. Use a pieced form-clamp if a full metal holddown plate or hardwood cutout is not available or if a full cutout cannot be used. Be careful to clamp them properly and locate them so that they line up with the edge of the form. If they are not lined up accurately, the material will bulge.

(6) After preparing and checking the form, perform the bumping process as follows:

(a) Cut a metal blank to size, allowing an extra 1/2 to 1 inch to permit drawing.

(b) Apply a thin coat of light oil to the block and to the aluminum to prevent galling (scraping on rough spots).

(c) Clamp the material between the block and steel plate so that it will be firmly supported yet able to slip a little toward the inside of the form.

(d) Clamp the bumping block in a bench vise. With a soft-faced mallet or with a hardwood drive block and suitable mallet, start the bumping near the edges of the form.

(e) With light blows of the mallet, work the material down gradually from the edges. Remember that the object of the bumping process is to work the material into shape by stretching it, rather than by forcing it into the form with heavy blows. Always start bumping near the edge of the form; never start near the center of the blister.

(f) Smooth the work as much as possible before removing it from the form. Accomplish this by rubbing the work with the rounded end of a maple block or with the round end of a stretching mallet.

(g) Remove the blister from the bumping block and trim it, leaving a 1/2-inch flange.

(h) Finally, drill the rivet holes, chamfer the edges 45°, and clean and polish the part.

b. Sandbag Bumping. Bumping on a sandbag is one of the most difficult types of sheet metal hand-forming, as there is no exact form block to serve as a guide. For this type of forming operation, depression must be forced into a sandbag to take the shape of the hammered portion of the metal. The depression, or pit, has tendency

to more or less shift from the hammering. This necessitates readjusting from time to time during the bumping process. The degree of shifting depends largely on the contour or shape of the piece being formed, and whether glancing blows must be struck in order to stretch, draw, or shrink the metal. When forming by this method, prepare a contour template or some sort of a pattern to serve as a working guide and to insure accuracy of the finished part. Make the pattern from ordinary kraft or similar paper, folding it over the part to be duplicated. Cut the paper cover at the points where it would have to be stretched to fit, and attach additional pieces of paper with masking tape to cover the exposed portions. After completely covering the part, trim the pattern to exact size. Open the pattern and spread it out on the metal from which the part is to be formed. Although the pattern will not lie flat, it will give a fairly accurate idea of the approximate shape of the metal to be cut, and the pieced-in sections will indicate where the metal is to be stretched. When the pattern has been placed on the material, mark the outline of the part and the portions to be stretched with pencil. Add at least 1 inch of excess metal when cutting the material to size. The excess metal can be trimmed off after bumping the part into shape. If the part to be formed is radially symmetrical, it will be fairly easy to shape since a simple contour template can be used as a working guide, making a pattern to indicate the portions of unequal stretching unnecessary. However, the procedure for bumping sheet metal parts on a sandbag follows certain basic rules which can be applied to any part, regardless of its contour or shape. Proceed as follows.

(1) Lay out and cut the contour template. (This can be made of sheet metal, medium-heavy cardboard, or thin plywood.)

(2) Determine the amount of metal needed, lay it out, and cut it to size, allowing at least 1/2 inch excess.

(3) Place a sandbag on a solid foundation capable of supporting heavy blows and, with the aid of a smooth-faced mallet, make a pit in the bag. Analyze the part to determine the correct radius of the pit for the forming operation. The pit will change with the hammering it receives and must be readjusted occasionally.

(4) Select a soft round-faced or bell-shaped mallet having a contour slightly smaller than the contour desired on the sheet metal part. Holding one edge of the metal in the left hand, place the portion to be bumped near the edge

of the pit on the sandbag. Strike the metal with light, glancing blows, about 1/2 to 1 inch from the edge.

(5) Continue bumping toward the center, revolving the metal and working gradually inward until the desired shape is obtained. Shape the entire part as a unit.

(6) At frequent intervals during the bumping process, check the part for accuracy of shape by applying the template. If wrinkles are formed, work them out before they become too large.

(7) Finally, with a suitable stake and planishing hammer, or with a hand dolly and planishing hammer, remove small dents and hammer marks.

(8) With a pair of dividers, mark around the outside of the object. Trim the edge and file smooth. Clean and polish the part.

94. Jogging

A joggle is an offset formed on an angle strip to allow clearance for a sheet or an extrusion. Joggles are often found at the intersection of stringers and formers. One of these members, usually the former, has the flange joggled to fit flush over the flange of the stringer. The amount of offset is usually small; therefore, the depth of the joggle is generally specified in thousandths of an inch. The thickness of the material to be cleared governs the depth of the joggle. In determining the length of the joggle necessary, it is common practice to allow 1/16 inch to give enough added clearance to assure a fit between the joggled, overlapped part. There are a number of different methods to form joggles.

a. *Joggle on a Straight Flange.* If the joggle is to be made on a straight flange or flat piece of metal, form it on a cornice brake by inserting and bending up along the line of the joggle. Hold a piece of metal of the correct thickness to give the desired offset under the bent-up portion, and pound the flange down while the metal is still in the same position in the brake.

b. *Joggle on a Curved Flange.* Where a joggle is necessary on a curved flange, forming blocks or dies made of hardwood, steel, or aluminum alloy may be used. If the die is to be used only a few times, hardwood is satisfactory as it is easily worked. If a number of similar joggles are to be produced, use steel or aluminum alloy dies. Dies of aluminum alloy are preferred, since they are easier to fabricate than those of steel and will wear about as long. They are sufficiently

soft and resilient to permit forming aluminum alloy parts on them without marring, and nicks and scratches are easily removed from their surfaces.

Note. When using joggling dies for the first time, test them for accuracy on a piece of waste stock to avoid the possibility of ruining already fabricated parts. Always keep the surfaces of the blocks free from dirt, filings, and the like, so that the work will not be marred.

CHAPTER 7

RIVETS, SPECIAL PURPOSE BOLTS, AND RESISTANCE WELDING

Section I. GENERAL

95. Methods of Holding Metal Together

An aircraft, even though made of the best materials and strongest parts, would be of doubtful value unless those parts were firmly held together. Several methods are used to hold metal parts together; they include riveting, bolting, brazing, and welding. The process used must produce a union that will be as strong as the parts that are joined. The methods discussed of holding metal together in this chapter are riveting, using special purpose bolts, and resistance welding.

96. Rivet Description

a. A rivet is a metal pin used to hold two or more metal sheets, plates, or pieces of material together. A head is formed on one end when the rivet is manufactured. The shank of the rivet is placed through matched holes in two pieces of material, and the tip is then mushroomed over to form a second head to clamp the two pieces securely together. The second head, formed

either by hand or by pneumatic equipment, is called a shop head. The shop head functions in the same manner as a nut on a bolt.

b. Rivets are divided into two main groups: common solid shank rivets and special rivets. The latter are for use in special cases.

97. Welding Description

Welding is a method of adding to metal parts, or fastening them together. The combining of two pieces of metal without loss of strength is the prime object of all welding. Electric resistance welding has solved a production problem with a decrease in labor, dirt, noise, and time. One advantage in using electric resistance welding is definite localization of heating at the junction where fusion is desired with accurate control of both heat and the extent of fusion. No addition of filler metal to the weld is required. This process permits welding of pieces having difficult physical shape and different physical characteristics.

Section II. SOLID SHANK RIVETS

98. Rivet Materials and Usage

The material used for the majority of aircraft solid shank rivets is aluminum alloy. The strength and temper conditions of aluminum alloy rivets are identified by digits and letters similar to those adopted for the identification of strength and temper conditions of aluminum and aluminum alloy sheet stock.

a. Aluminum Rivets.

(1) *1100 rivets.* The 1100 rivet, which is composed of 99.00 percent pure aluminum, is very soft. It is for riveting the softer aluminum alloys which are used for nonstructural parts (all parts where strength is not a factor). The riveting of map cases is an example of its use.

(2) *2117-T4 rivets.* The 2117-T4 rivet is used more than any other for riveting aluminum alloy structures. Its main advantage lies in the fact that it is ready for use as received

and needs no further heat-treating or annealing. It also has a high resistance to corrosion.

(3) *2017- and 2024-T4 rivets.* The 2017- and 2024-T4 rivets are used where more strength is needed than is obtainable with the 2117-T4 rivet.

(4) *5056 rivets.* The 5056 rivet is used for riveting magnesium alloy structures. It has high corrosion-resistant qualities and can be driven in the "as is" condition.

b. Steel Rivets.

(1) *Mild steel rivets.* Mild steel rivets are used for riveting steel parts. Galvanized rivets should not be used on steel parts subjected to high heat.

(2) *Corrosion-resistant steel rivets.* Corrosion-resistant steel rivets are used primarily in riveting corrosion-resistant steel parts, such as

firewalls, exhaust stack bracket attachments, and similar structures.

c. Monel Rivets. Monel rivets are used in special cases for riveting high nickel-steel alloys and nickel alloys. Monel rivets may be used interchangeably with corrosion-resistant steel rivets and are easier to drive. However, it is preferable to use stainless steel rivets with stainless steel parts.

d. Copper Rivets. Copper rivets are used for riveting copper alloys, leather, and other non-metallic materials. Copper rivets have only limited usage in aircraft.

99. Rivet Identification

a. Different markings on the heads of rivets are used to classify their characteristics (fig. 143). These markings may be either a dimple, a raised teat, a pair of raised dashes, a raised cross, a recessed triangle, or a pair of recessed dimples; some other heads have no markings. The different markings indicate the composition of the rivet stock. Rivets with heads that have no markings, or plain heads, can be distinguished by their color; the 1100 rivet is aluminum color, the mild steel is a typical steel color, and the copper rivet is a copper color. Aluminum and aluminum alloy rivets are also packaged in boxes bearing colored labels. The color of the label will indicate the composition of the rivets inside the box. The rivets and the corresponding label color are: 1100, white; 2117-T4, orange; 2017-T4, yellow; 2024-T4, red; and 5056, blue.

b. Table 27 gives the first and second dash numbers for MS rivets. The first dash number designates diameter of the rivet in thirty-seconds of an inch and the second dash number designates the length of the rivet in sixteenths of an inch. A letter or letters in an MS rivet part number following the basic MS standard number, indicates the rivet composition. The absence of a letter indicates the rivet is manufactured from carbon or mild steel. An example of a complete rivet part number is shown in figure 143. Head dimensions are given in figure 144.

100. Heat-Treating of Ice Box Rivets

a. Temper is an important factor in the riveting process, especially with aluminum alloy rivets. Aluminum alloy rivets have the same heat-treating characteristics as aluminum alloy sheet stock. They can be hardened and annealed in the same manner as sheet aluminum. The rivet must be soft, or comparatively soft, before a good shop head can be formed. The 2017- and 2024-T4 rivets are softened by heat-treating before being driven. They harden with age.

b. Rivets are heat-treated in accordance with MIL-H-6875 and MIL-H-6088. To accomplish heat-treatment, an electric air furnace or a salt bath is required. The heat-treating temperature ranges from 910° to 950°F. (488° to 510°C.) depending on the alloy being treated. For convenient handling, rivets are heated in a tray or a wire basket. Immediately after heat-treating, the rivets are quenched in water at a temperature of approximately 70°F. (21.1°C.).

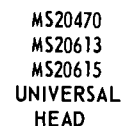
c. The 2017- and 2024-T4 rivets, which are heat-treatable rivets, begin to age-harden within a few minutes after being exposed to room temperature. Therefore, they must be used immediately after quenching or else be placed in cold storage. The most commonly used means for holding heat-treatable rivets at temperatures below 32°F. (0°C.) is to keep them in an electric refrigerator. They are referred to as *ice box* rivets. Under this storage condition, they will remain soft enough for driving for periods up to 2 weeks. Any rivets not used within that time should be removed for reheat-treating.

d. Ice box rivets attain about one-half of their maximum strength in approximately 1 hour after driving and full strength in about 4 days. When 2017-T4 rivets are exposed to room temperature for 1 hour or longer, they must be reheat-treated. This also applies to 2024-T4 rivets exposed to room temperature for a period exceeding 10 minutes.

e. Once an ice box rivet has been taken from the refrigerator, it should not be mixed with the rivets still in cold storage. If more rivets are removed from the ice box than can be used in 15 minutes, they should be placed in a separate container and stored for reheat-treating. Heat-treatment of rivets may be repeated a number of times if done properly. Proper heating times and temperatures are listed in table 28.

f. Reheating an excessive number of times will result in a gradual hardening of the rivets. Fifteen or more times is considered excessive. Figure 145 shows the heating and quenching equipment needed for heat-treating rivets. Rivets coated for corrosion resistance are never heated in a salt bath.

g. The head markings will identify the composition of a rivet. If the markings are not distinct, the hardness of the rivet can be determined by using the Rockwell hardness tester described in chapter 3. To use this machine, place the rivet on a V-block anvil, use the 1/16-inch ball penetrator, and apply a 60-kilogram load. A reading of 75 or over on the B scale indicates an age-hardened and heat-treatable rivet.



MATERIAL	HEAD MARKING	MS MATERIAL CODE	MS20426 CSK HEAD	MS20427 CSK HEAD	MS20470 UNIV HEAD	MS20613 UNIV HEAD	MS20615 UNIV HEAD	HEAT-TREAT BEFORE USING	STRENGTH (PSI)	
									SHEAR	BEARING
1100	PLAIN 	A	X		X			NO	10000	25000
2117	DIMPLED 	AD	X		X			NO	30000	100000
2017	RAISED TEAT 	D	X		X			YES	34000	113000
2024	RAISED DOUBLE DASH 	DD	X		X			YES	41000	136000
5056	RAISED CROSS 	B	X		X			NO	27000	90000
CARBON STEEL	RECESSED TRIANGLE 			X		X		NO	35000	90000
CORROSION-RESISTANT STEEL	PLAIN 	F		X		X		NO	75000	90000
MONEL, FEDERAL SPECIFICATION QQ-N-281	RECESSED DOUBLE DIMPLE 	M		X			X	NO	55000	
COPPER, FEDERAL SPECIFICATION QQ-W-341	PLAIN 	CU		X			X	NO	25000	

NOTES.

1. THE PREDOMINATING COLOR OF LABELS FOR BOXES OF M5 RIVETS ARE AS FOLLOWS:
(MILITARY SPECIFICATION, MIL-R-5674) 1100-WHITE; 2017-YELLOW; 2117-ORANGE; 5056-BLUE.
2. ALL STRENGTH CALCULATIONS FOR RIVETS SHOULD BE BASED ON DIAMETER OF RIVET.
3. RIVET SPECIFICATION, MIL-R-5674, COVERS MATERIALS TYPES A, AD, B, D, AND DD LISTED ABOVE, ALL ALUMINUM ALLOY RIVETS ARE ANODIZED.
4. AN EXAMPLE RIVET NUMBER CODE IS AS FOLLOWS:

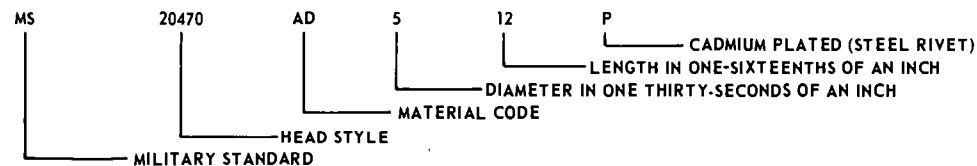


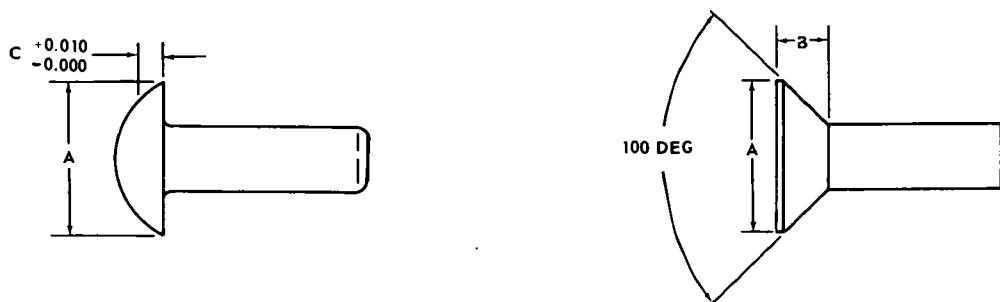
Figure 143. MS rivet identification.

Table 27. MS Rivet Dash Numbers

DIA	LENGTH AND DASH NUMBERS																								
	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$1\frac{1}{8}$ (Note 3)	$\frac{3}{4}$ (Note 3)	$1\frac{3}{8}$ (Note 3)	$\frac{7}{8}$	$1\frac{1}{2}$ (Note 3)	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4
$\frac{1}{16}$	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9	2-10		2-12		2-14		2-16	2-18	2-20								
$\frac{3}{32}$	3-2	3-3	3-4	3-5	3-6	3-7	3-8	3-9	3-10		3-12		3-14		3-16	3-18	3-20	3-22							
$\frac{1}{8}$		4-3	4-4	4-5	4-6	4-7	4-8	4-9	4-10	4-11	4-12	4-13	4-14	4-15	4-16	4-18	4-20	4-22	4-24	4-28					
$\frac{5}{32}$			5-4	5-5	5-6	5-7	5-8	5-9	5-10	5-11	5-12	5-13	5-14	5-15	5-16	5-18	5-20	5-22	5-24	5-28	5-32				
$\frac{3}{16}$			6-4	6-5	6-6	6-7	6-8	6-9	6-10	6-11	6-12	6-13	6-14	6-15	6-16	6-18	6-20	6-22	6-24	6-28	6-32	6-40	6-48		
$\frac{7}{32}$ (NOTE 2)					7-6	7-7	7-8	7-9	7-10		7-12		7-14		7-16	7-18	7-20	7-22	7-24	7-28	7-32	7-40	7-48	7-56	
$\frac{1}{4}$				8-5	8-6	8-7	8-8	8-9	8-10	8-11	8-12	8-13	8-14	8-15	8-16	8-18	8-20	8-22	8-24	8-28	8-32	8-40	8-48	8-56	
$\frac{5}{16}$						10-7	10-8	10-9	10-10		10-12		10-14		10-16	10-18	10-20	10-22	10-24	10-28	10-32	10-40	10-48	10-56	10-64
$\frac{3}{8}$							12-8	12-9	12-10		12-12		12-14		12-16	12-18	12-20	12-22	12-24	12-28	12-32	12-40	12-48	12-56	12-64

NOTES:

1. Identification of MS20426, MS20427, MS20613, MS20615, and MS20470 rivets.
2. Available only in MS20470 rivets.
3. Available only in MS20615 rivets.
4. Examples of part numbers: MS20426D3-12 = Rivet, 2017-T4 aluminum alloy, $\frac{3}{16}$ -inch dia, $\frac{3}{4}$ inch long.
MS20427M2-2 = Monel rivet, $\frac{1}{16}$ -inch dia, $\frac{1}{8}$ inch long.
MS20613-4P14 = Universal-head rivet, carbon steel, cadmium plated, $\frac{1}{8}$ -inch dia, $\frac{1}{8}$ inch long.
MS20615-2M8 = Universal-head rivet, nickel copper alloy, $\frac{1}{16}$ -inch dia, $\frac{1}{2}$ inch long.
MS20470A2-12 = Rivet, 1100 aluminum, $\frac{1}{16}$ -inch dia, $\frac{3}{4}$ inch long.
5. Dimensions shown are in inches.



UNIVERSAL HEAD							COUNTERSUNK HEAD			
RIVET DIAMETER	MS20470		MS20613		MS20615		MS20426		MS20427	
	A	C	A	C	A	C	A	B	A	B
1/16	0.125 ± 0.006	0.027	0.125 ± 0.006	0.027	0.125 ± 0.006	0.027	0.114 ± 0.004	0.022	0.135 ± 0.004	0.032
3/32	0.187 ± 0.009	0.040	0.187 ± 0.009	0.040	0.187 ± 0.009	0.040	0.179 ± 0.004	0.036	0.190 ± 0.004	0.042
1/8	0.250 ± 0.012	0.054	0.250 ± 0.012	0.054	0.250 ± 0.012	0.054	0.225 ± 0.004	0.042	0.236 ± 0.004	0.048
5/32	0.312 ± 0.016	0.067	0.312 ± 0.016	0.067	0.312 ± 0.016	0.067	0.286 ± 0.004	0.055	0.298 ± 0.004	0.061
3/16	0.375 ± 0.019	0.080	0.375 ± 0.019	0.080	0.375 ± 0.019	0.080	0.353 ± 0.004	0.070	0.365 ± 0.004	0.075
7/32	0.437 ± 0.022	0.093					0.415 ± 0.004	0.083		
1/4	0.500 ± 0.025	0.107	0.500 ± 0.025	0.107	0.500 ± 0.025	0.107	0.476 ± 0.004	0.095	0.489 ± 0.004	0.103
5/16	0.625 ± 0.031	0.133	0.625 ± 0.031	0.133			0.564 ± 0.004	0.106	0.577 ± 0.004	0.115
3/8	0.750 ± 0.037	0.161	0.750 ± 0.037	0.161			0.694 ± 0.004	0.134	0.708 ± 0.004	0.144

NOTES:

1. EXAMPLES OF PART NUMBERS:

MS20470A2-12 - UNIVERSAL-HEAD RIVET, 1100 ALUMINUM, 1/16-INCH DIA, 3/4 INCH LONG.
 MS20613-4P14 - UNIVERSAL-HEAD RIVET, CARBON STEEL, CADMIUM PLATED, 1/8-INCH DIA, 7/8 INCH LONG.
 MS20615-2M5 - UNIVERSAL-HEAD RIVET, NICKEL COPPER ALLOY, 1/16-INCH DIA, 1/2 INCH LONG.
 MS20426D3-12 - COUNTERSUNK-HEAD RIVET, 100-DEGREE, ALUMINUM ALLOY, 2017-T4, 3/32-INCH DIA, 3/4 INCH LONG.
 MS20427M2-2 - COUNTERSUNK-HEAD RIVET, 100-DEGREE, MONEL, 1/16-INCH DIA, 1/8 INCH LONG.

2. DIMENSIONS SHOWN ARE IN INCHES.

Figure 144. MS rivet dimensions.

101. Rivet Layout

Rivet layout consists of determining: the number of rivets required; the size and style of rivets to use; its material, temper condition and strength; the size of the rivet holes; distance of the rivet holes and rivets from the edges of the patch; and the spacing of the rivets throughout the repair. Distances are measured in terms of rivet diameters. Single-row, two-row, and three-row layouts designed for small repair jobs are discussed in this paragraph. More complicated layouts for large repairs, which require the application of rivet formulas, are discussed in chapter 9.

a. Selection of Rivets. The type of head, size, and strength required in a rivet are governed by such factors as the kind of forces present at the point riveted, the kind and thickness of the material to be riveted, and location of the riveted part on the aircraft. The type of head required for a particular job is determined by

its installation location. Where a smooth aerodynamic surface is required, countersunk head rivets should be used. Universal head rivets may be used in most other locations.

(1) *Rivet diameter.* The size (or diameter) of the selected rivet shank should correspond in general to the thickness of the material being riveted. If too large a rivet in a thin material is used, the force necessary to drive the rivet properly will cause an undesirable bulging around

Table 28. Rivet Heating Time and Temperatures

Rivet alloy	Temperature	Time	
		Air furnace	Salt bath
2024	910° to 930° F. (488° to 499° C.)	1 hr	30 min
2017	925° to 950° F. (496° to 510° C.)	1 hr	30 min

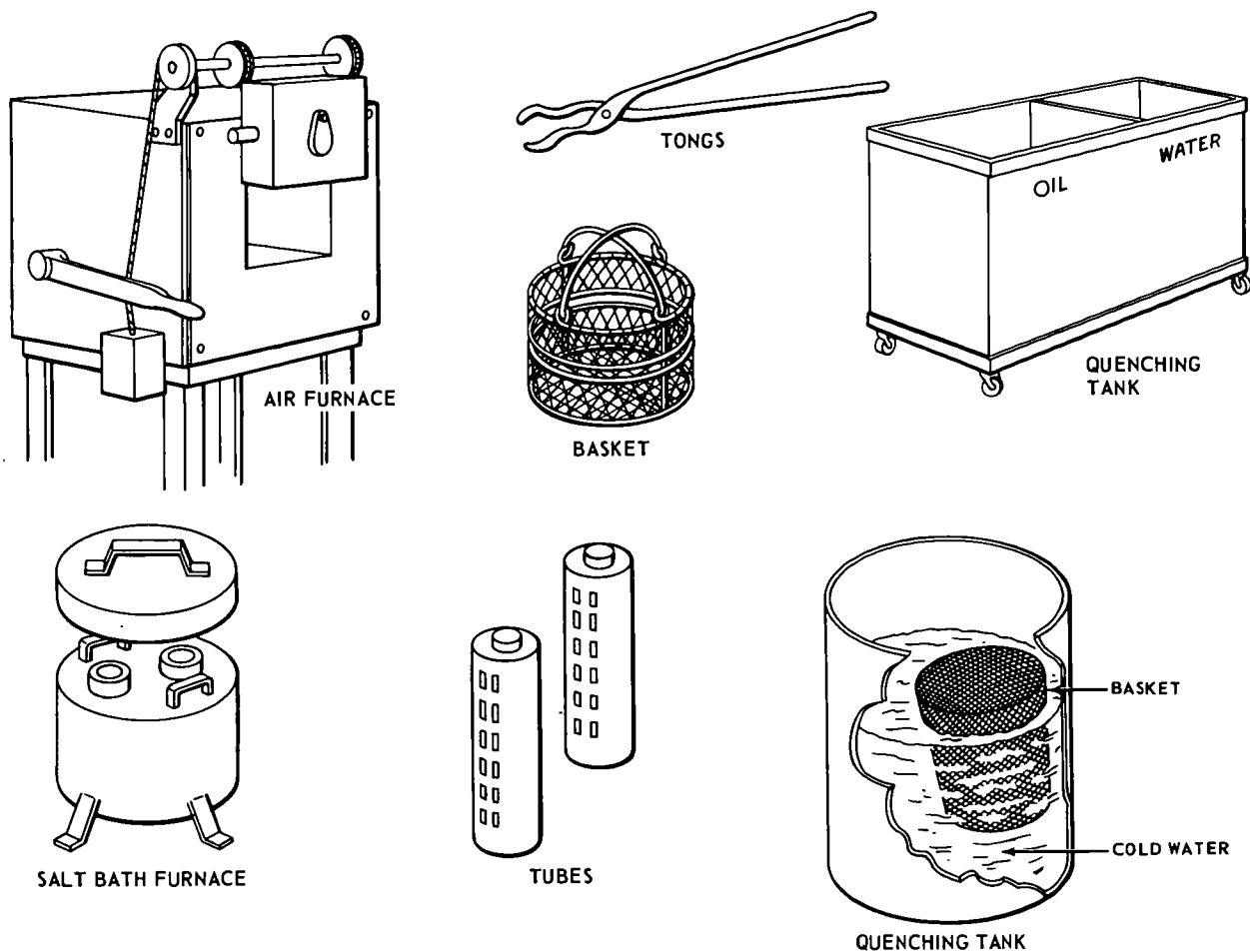


Figure 145. Heating and quenching equipment.

the rivet head. On the other hand, if too small a rivet diameter for thick material is used, the shear strength of the rivet will not be great enough to carry the load of the joint. As a general rule, the rivet diameter should not be less than the combined thickness of the component parts of the joint, nor more than $2\frac{1}{2}$ to 3 times the thickness of the sheet. Rivets most commonly chosen in the assembly and repair of aircraft range from $\frac{3}{32}$ -inch to $\frac{3}{8}$ -inch diameter. Ordinarily, rivets smaller than $\frac{3}{32}$ inch in diameter are never used on any structural parts which carry stresses. When rivets are to pass completely through tubular members, select a rivet diameter equivalent to at least $\frac{1}{8}$ the outside diameter of the tube. If one tube sleeves or fits over another, take the outside diameter of the outside tube and use $\frac{1}{8}$ of that distance as the minimum rivet diameter. A good practice is to calculate the minimum rivet diameter and then use the next larger size rivet.

(2) *Rivet length.* When determining the total length of a rivet for installation, the combined thickness of the materials to be joined

must be known. This measurement is known as grip length (B, fig. 146). The total length of the rivet (A, fig. 146), is equal to the grip length plus the amount of rivet shank necessary to form a proper shop head. The length of rivet required to form a shop head is $1\frac{1}{2}$ times the diameter of the rivet shank (C, fig. 146). Using figure 146 and the above information, we determine that $A = B + C$ (A, total rivet length; B, grip length; C, material needed to form a shop head). Properly installed rivets are shown as D in figure 146. Grip lengths for universal and countersunk-head, solid-shank rivets are listed in table 29.

(3) *Corrosion resistance.* Corrosion must be considered when choosing aircraft rivets. Almost all metals, and therefore aircraft rivet stocks, are subject to corrosion. Corrosion may be the result of local climate conditions and/or the fabrication process used. It is reduced to a minimum by using metals which are highly resistant to corrosion. Corrosion resistance is generally considered adequate when the rivet material is of the same, or almost the same type as that of the structure being riveted, provided the proper anticorrosion surface treatment has been applied.

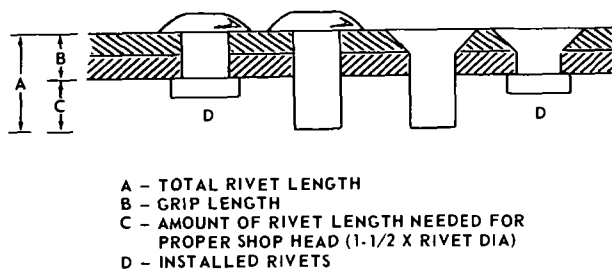


Figure 146. Determining length of rivet.

(4) *Strength.* For structural application, strength of the replacement rivet is of primary importance. Replacements with rivets of lower strength material should not be made unless the difference in strength is made up by the use of a larger rivet. For example, a rivet of 2024-T4 aluminum alloy should not be replaced with one made of 2117-T4 or 2017-T4 aluminum alloy unless the next larger size is used. Allowable shear strength for universal-head, dimple countersunk, and machine countersunk aluminum alloy rivets is given in table 30.

(5) *Number required.* To determine the number of rivets required to restore full strength to any repair, refer to the rivet formula (para 147e). Since the number of rivets calculated by this formula will exceed strength requirements for most Army aircraft, the following rule of thumb will generally apply: To determine the number of rivets required on each side of the break, multiply the length of break, in inches, by four or five. The number used should never be less than four times the length of the break but may exceed five times the length of the break in some cases. For square or rectangular skin cutouts, the length of the break is the longest dimensions (diagonal).

b. *Spacing of Rivets.* In general, the spacing of rivets on a repair should conform to that used by the manufacturer in the area surrounding the damage. Aside from this fundamental rule, there is no specific set of rules which governs spacing of rivets in all cases. However, there are certain minimum requirements which must be observed.

(1) *Edge distance.* The edge distance, or

distance from the center of the first rivet to the edge of the sheet, should be not less than two rivet diameters nor more than four. The recommended edge distance is about two and one-half rivet diameters. If rivets are placed too close to the edge of the sheet, the sheet is likely to crack or pull away from the rivets; and if they are spaced too far from the edge, the sheet is apt to turn up at the edges.

(2) *Pitch distance.* Rivet pitch is the distance between the centers of neighboring rivets in the same row. The smallest allowable rivet pitch is three rivet diameters. The average rivet pitch usually ranges from six to eight rivet diameters, although rivet pitch may range from four to ten rivet diameters. Transverse pitch is the perpendicular distance between rivet rows; it is usually equal to 75 percent of the rivet pitch. The smallest allowable transverse pitch is two and one-half rivet diameters.

(3) *Example of rivet spacing.* The general rules of rivet spacing, as applied to straight-row layout, are quite simple. In a single-row layout, first determine the edge distance at each end of the row, then lay off the rivet pitch (distance between rivets) as shown in figure 147. In the two-row layout, lay off the first row as just described, place the second row a distance equal to the transverse pitch from the first row, and then lay off rivet spots in the second row so they fall midway between those in the first row. In the three-row layout, first lay off the first and third rows, then determine the second row rivet spots by using a straightedge. When splicing a damaged tube and the rivets pass completely through the tube, space the rivets four to seven rivet diameters apart if neighboring rivets are at right angles to each other, and space them five to seven rivet diameters apart if the rivets are in line (parallel to each other). The first rivet on each side of the joint should not be less than 2 1/2 rivet diameters from the end of the sleeve.

102. Rivet Installation

a. Equipment Required.

(1) *Special riveting hand tools.* Special riveting hand tools used in the normal course of driving and upsetting rivets include hole duplicators, rivet cutters, bucking bars, hand rivet and draw sets, countersinks, and dimpling dies. Drills, reamers, and C-clamps needed for installation of rivets were discussed in chapter 4.

(a) *Hole duplicators.* When sections of skin are replaced with new sections, the holes in the replacement sheet or in the patch must be drilled to match existing holes in the structure. These holes can be located with a hole

Table 29. Grip Lengths for Solid Shank Rivets

CORRECT RIVET LENGTHS FOR UNIVERSAL—HEAD RIVETS						
DIAMETER		$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{1}{4}$
LENGTH OF RIVET (SEE NOTE 1.)	DASH NUMBER FOR RIVET	GRIP	GRIP	GRIP	GRIP	GRIP
$\frac{1}{8}$	-2	0	0	0	0	0
$\frac{3}{16}$	-3	0.047	0	0	0	0
$\frac{1}{4}$	-4	0.109	0.062	0.016	0	0
$\frac{5}{16}$	-5	0.171	0.124	0.078	0.031	0
$\frac{3}{8}$	-6	0.234	0.187	0.141	0.094	0
$\frac{7}{16}$	-7	0.297	0.250	0.204	0.157	0.063
$\frac{1}{2}$	-8	0.359	0.312	0.266	0.219	0.125
$\frac{9}{16}$	-9	0.421	0.374	0.328	0.281	0.187
$\frac{5}{8}$	-10	0.484	0.437	0.391	0.344	0.250
$1\frac{1}{16}$	-11	0.547	0.500	0.454	0.407	0.313
$\frac{3}{4}$	-12	0.609	0.562	0.516	0.469	0.375
$1\frac{3}{16}$	-13	0.671	0.624	0.578	0.531	0.437
$\frac{7}{8}$	-14	0.734	0.687	0.641	0.594	0.500
$1\frac{5}{16}$	-15	0.796	0.749	0.703	0.656	0.562
1	-16	0.859	0.812	0.766	0.719	0.625

CORRECT RIVET LENGTHS FOR COUNTERSUNK—HEAD RIVETS						
$\frac{1}{8}$	-2	0	0	0	0	0
$\frac{3}{16}$	-3	0.047	0	0	0	0
$\frac{1}{4}$	-4	0.109	0.062	0.016	0	0
$\frac{5}{16}$	-5	0.171	0.124	0.078	0.031	0
$\frac{3}{8}$	-6	0.234	0.187	0.141	0.094	0
$\frac{7}{16}$	-7	0.297	0.250	0.204	0.157	0.063
$\frac{1}{2}$	-8	0.359	0.312	0.266	0.219	0.125
$\frac{9}{16}$	-9	0.421	0.374	0.328	0.281	0.187
$\frac{5}{8}$	-10	0.484	0.437	0.391	0.344	0.250
$1\frac{1}{16}$	-11	0.547	0.500	0.454	0.407	0.313
$\frac{3}{4}$	-12	0.609	0.562	0.516	0.469	0.375
$1\frac{3}{16}$	-13	0.671	0.624	0.578	0.531	0.437
$\frac{7}{8}$	-14	0.734	0.687	0.641	0.594	0.500
$1\frac{5}{16}$	-15	0.796	0.749	0.703	0.656	0.562
1	-16	0.859	0.812	0.766	0.719	0.625

NOTES:

1. When grip length falls between those given in the tables, select longer rivet. Grip = Total material thickness. If rivet of proper length is not available, cut off longer rivet to exact length, not grip, required.
2. Dimensions shown are in inches.

duplicator. The peg on the bottom leg of the duplicator fits into the existing rivet hole. The hole in the new part is made by drilling through the bushing on the top leg. If the duplicator is properly made, holes drilled in this manner will be

in perfect alignment. A separate duplicator must be used for each diameter of rivet.

(b) *Rivet cutters.* Rivet cutters are used to cut rivets to the desired length in case rivets of the needed length cannot be obtained. When

Table 30. Single Shear Strength of Aluminum Alloy Rivets

UNIVERSAL—HEAD RIVETS								
RIVET DIAMETER	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$
2117-T4	106	217	389	596	860	1556	2458	3511
2017-T4	120	246	441	675	974	1764	2786	3979
2024-T4	144	296	532	814	1175	2127	3359	4798
5056	95	195	347	536	774	1400	2210	3160
100-DEGREE DIMPLE COUNTERSUNK								
2117-T4		276	480	735	1020			
2017-T4		300	530	810	1130			
2024-T4		350	620	950	1325			
100-DEGREE MACHINE COUNTERSUNK								
2117-T4		186	331	518	745			
2017-T4		206	368	574	828			
2024-T4		241	429	670	966			
Ultimate Shear Strength:								
2117-T4				30000 psi				
2017-T4				34000 psi				
2024-T4				41000 psi				
5056				27000 psi				

NOTES:

1. Shear strength shown is in pounds.
2. Dimensions shown are in inches.

using a rotary rivet cutter, insert the rivet in the correct hole, place the required number of shims under the rivet head, and squeeze as if squeezing a pair of pliers. Rotation of the discs will cut the rivet to give the right length (as determined by the number of shims inserted under the head). When using the large rivet cutter, place it in a vise, insert the rivet in the proper hole, and cut by pulling the handle, thus shearing off the rivet. If regular rivet cutters are not available, diagonal cutting pliers can be used as an emergency cutter.

(c) *Bucking bars*. A bucking bar is a tool which is held against the shank end of a rivet while the shop head is being formed. Most bucking bars are made of alloy bar stock; but those made of better grades of steel last longer and require less reconditioning. Bucking bars are made in a number of different shapes and sizes to facil-

itate rivet bucking in all places where rivets are used. Some of the various bucking bars are shown in figure 148. The bars must be kept clean, smooth, and well polished. Their edges should be slightly rounded to prevent marring the material surrounding the riveting operation. The face of the bar is usually concave to conform to the shape of the shop head to be made. The face should have a radius slightly larger than the thin head to insure solid bucking and to prevent marring the material to be riveted. Six pounds is the average weight of bucking bars. These bars are sometimes called *dollies*, *bucking irons*, or *bucking blocks*. Inaccessible areas require special bars to accomplish the riveting operation. The expanding bucking bar shown in figure 149 is such a tool. It is a steel block whose diameter or width can be adjusted. It is attached to the end of a hollow steel shaft which

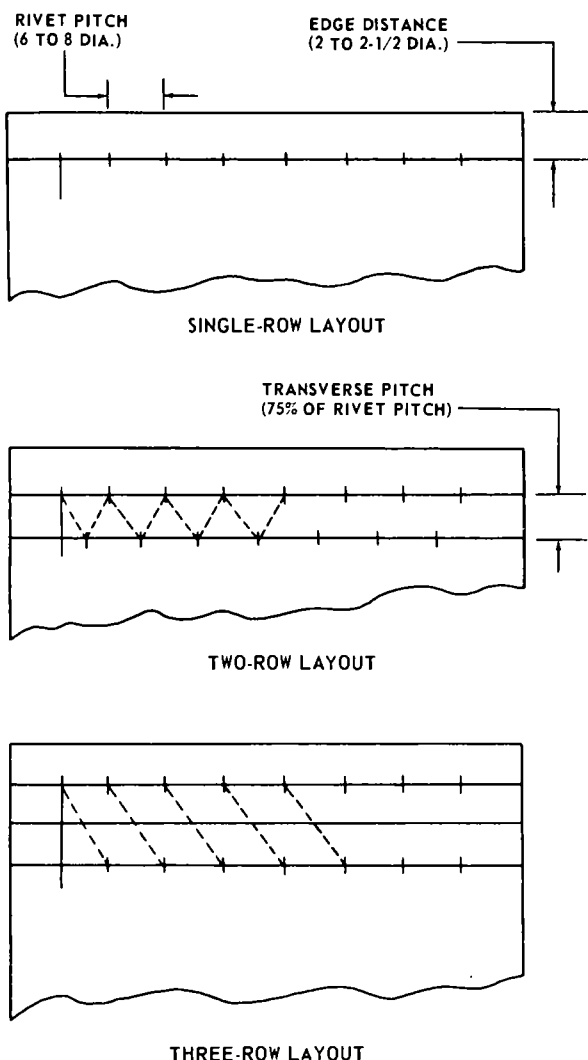


Figure 147. Rivet spacing.

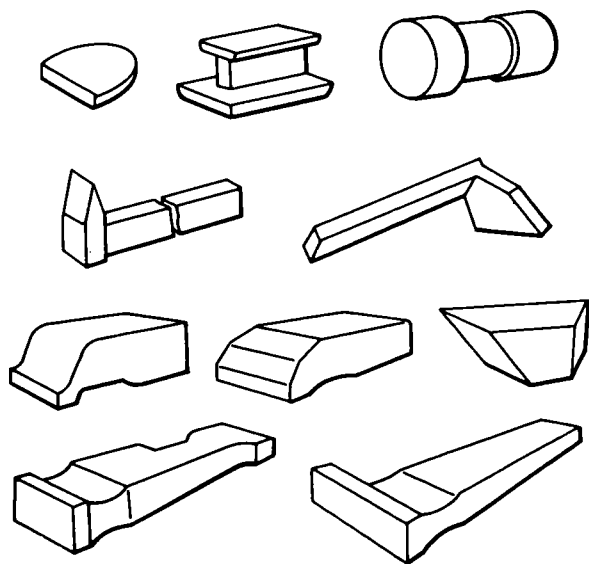


Figure 148. Bucking bars.

contains a bar that can be twisted to expand or reduce the width of the block. An expanding bucking bar is used to buck rivets on the inside of tubular structures or in similar spaces that cannot be reached by regular bucking bars. The space must be small enough for one side of the partially expanded block to press against the tip of the rivet's shank and for the other side to press against a strong supporting surface. Expanding bucking bars speed up the process of riveting the skin on wing sections.

(d) *Hand rivet and draw sets.* A hand rivet set is a punch-like tool equipped with a die for driving a particular type rivet. The ordinary set is made of 1/2-inch carbon tool steel about 6 inches long and knurled to prevent slipping in the hand. Only the face of the set is hardened and polished. Special draw sets are used to draw up the sheets in order to eliminate any opening between them before the rivet is bucked. Each draw set has a hole 1/32-inch larger than the diameter of the rivet shank for which it is made. Occasionally, the draw set and rivet header are incorporated into one tool. The header part consists of a hole sufficiently shallow so that the set will expand the rivet and head it when struck with a hammer.

(e) *Countersinks.* The countersinks is a tool which cuts a cone-shaped depression around the rivet hole to allow the rivet to set flush with the surface of the skin. Countersinks are made with various angles to correspond to the various angles of the countersunk rivet heads. The angle of the standard countersink shown in figure 60 is 100°. Special stop countersinks are available. The stop countersink shown in figure 60 is adjustable to any desired depth and the cutters are interchangeable so that holes of various countersunk angles may be made. Some stop countersinks have a micrometer set arrangement, in increments of 0.001 inch, for adjusting the cutting depths.

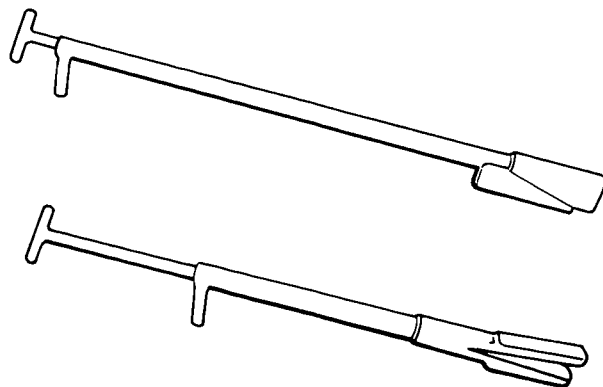


Figure 149. Expanding bucking bars.

(f) *Dimpling dies.* The process of making an indentation or a dimple around a rivet hole so the top of the head of a countersunk rivet will be flush with the surface of the metal is called dimpling. Dimpling is done with a male and female die, often called punch and die set. The male die has a guide the size of the rivet hole and is beveled to correspond to the degree of countersink of the rivet head. The female die has a hole into which the male guide fits, and is beveled to a corresponding degree of countersink. Thermo-dimpling uses a solid female die for the radius dimpling process and a solid ram female die for the coin dimpling process (fig. 150). Dimpling dies are made to correspond to any size and degree of countersunk rivet head available. The dies are usually numbered, and the correct combination of punch and die to use is indicated on charts specified by the manufacturer. Both male and female dies are machined accurately and have highly polished surfaces. The male die or punch is cone-shaped to conform to the rivet head and has a small concentric pilot shaft that fits into the rivet hole and female die. In some cases, the face of the male die is convex to allow for springback in the metal. Dies of this type are used to advantage when the sheet to be dimpled is curved. Dies with flat faces are principally used for flat work. Dimpling dies for light work can be used in portable pneumatic or hand squeezers. If the dies are used with a squeezer, they must be adjusted to the thickness of the sheet being dimpled.

(2) *Special power tools.* Special power tools used in the normal course of driving and upsetting rivets include pneumatic rivet guns, rivet squeezers, and microshavers. For larger work and mass production, stationary equipment, such as the bench riveter, is often used. However, stationary equipment is seldom used in airframe, repair; therefore, only portable equipment is discussed here.

(a) *Pneumatic rivet guns.* The most common upsetting tool used in airframe repair work

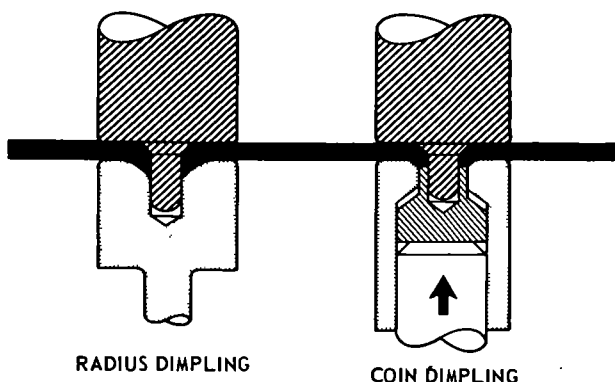
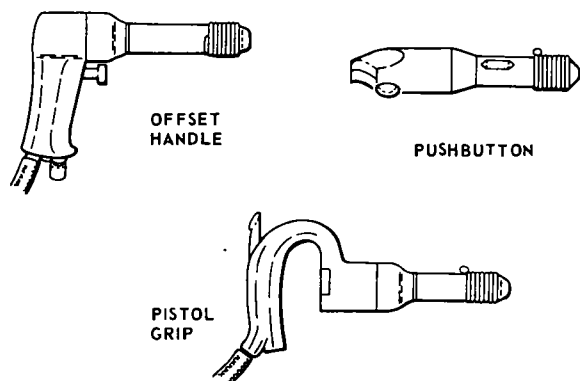


Figure 150. Radius and coin dimpling dies.

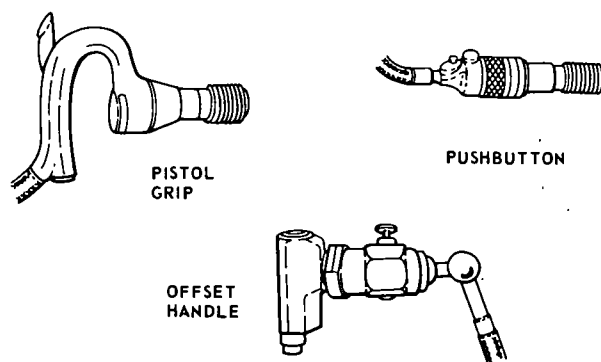
is the pneumatic hammer, called a rivet gun. Pneumatic guns are available in various sizes and shapes as shown in figure 151. The capacity of each gun, as recommended by the manufacturer, is usually stamped on the barrel. Pneumatic guns operate on air pressures of 90 to 100 psi. Pneumatic guns are used in conjunction with interchangeable rivet sets. Each set is designed to fit the type of rivet and location of the work. The shank of the set is designed to fit into the rivet gun. Force to buck the rivet is supplied by an air-driven hammer inside the barrel of the gun (fig. 152). Precautions to be observed when using a rivet gun are—

1. The gun should never be pointed at anybody at any time.
2. Never depress the trigger mechanism unless the set is held tightly against a block of wood or a rivet.
3. Never use the rivet gun as a toy. It is not a plaything but a tool to use in the right way to perform a job.
4. Always disconnect the air hose from the rivet gun when it will not be in use from any appreciable length of time.

(b) *Rivet squeezers.* The squeeze method of riveting is limited since it can be used only



SLOW-HITTING (LONG STROKE) RIVETING HAMMERS



FAST-HITTING (LIGHT) RIVETING HAMMERS

Figures 151. Types of rivet guns.

over the edges of sheets or assemblies where conditions permit, and where the reach of the rivet squeezer is deep enough. Rivet squeezers are of three types: hand, pneumatic, and pneudraulic (fig. 153). They are basically alike except that in the hand rivet squeezer, compression is supplied by hand pressure; in the pneumatic rivet squeezer, by air pressure; and in the pneudraulic rivet squeezer, by a combination of air and hydraulic pressure. One jaw is stationary and serves as a bucking bar; the other jaw is movable and does the upsetting. Some rivet squeezers are equipped with either a C-yoke or an alligator yoke to control the stroke of the plunger or movement of the movable jaw. Yokes are available in various sizes to accommodate any size of rivet. The working capacity of a yoke is measured by its gap and its reach. The gap is the distance between the movable jaw and the stationary jaw; the reach is the inside length of the throat measured from the center of the end sets. For squeezers not equipped with a gap regulator, the gap can be adjusted by placing metal shims under the end sets of both jaws, or by using end sets of different lengths. End sets

for rivet squeezers serve the same purpose as rivet sets for pneumatic rivet guns, and are available with the same type heads. They are interchangeable to suit any type of rivet head. One part of each set is inserted in the stationary jaw, while the other part is placed in the movable jaws. The manufactured head end set is placed on the stationary jaw when possible. However, during some operations, it may be necessary to reverse the end sets, placing the manufactured head end set on the movable jaw.

(c) *Microshaver*. If the smoothness of the material (such as skin) requires that all countersink rivets be driven within a specific tolerance, a microshaver is used. This tool has a cutter, a stop, and two legs or stabilizers as shown in figure 154. The cutting portion of the microshaver is located inside the stop. The depth of cut can be adjusted by pulling outward on the stop and turning it in either direction (clockwise for deeper cuts). The marks on the stop permit adjustments of 0.001 inch. If the microshaver is adjusted and held correctly, it will cut the head of a countersunk rivet to within 0.002 inch without damaging the surrounding material. Ad-

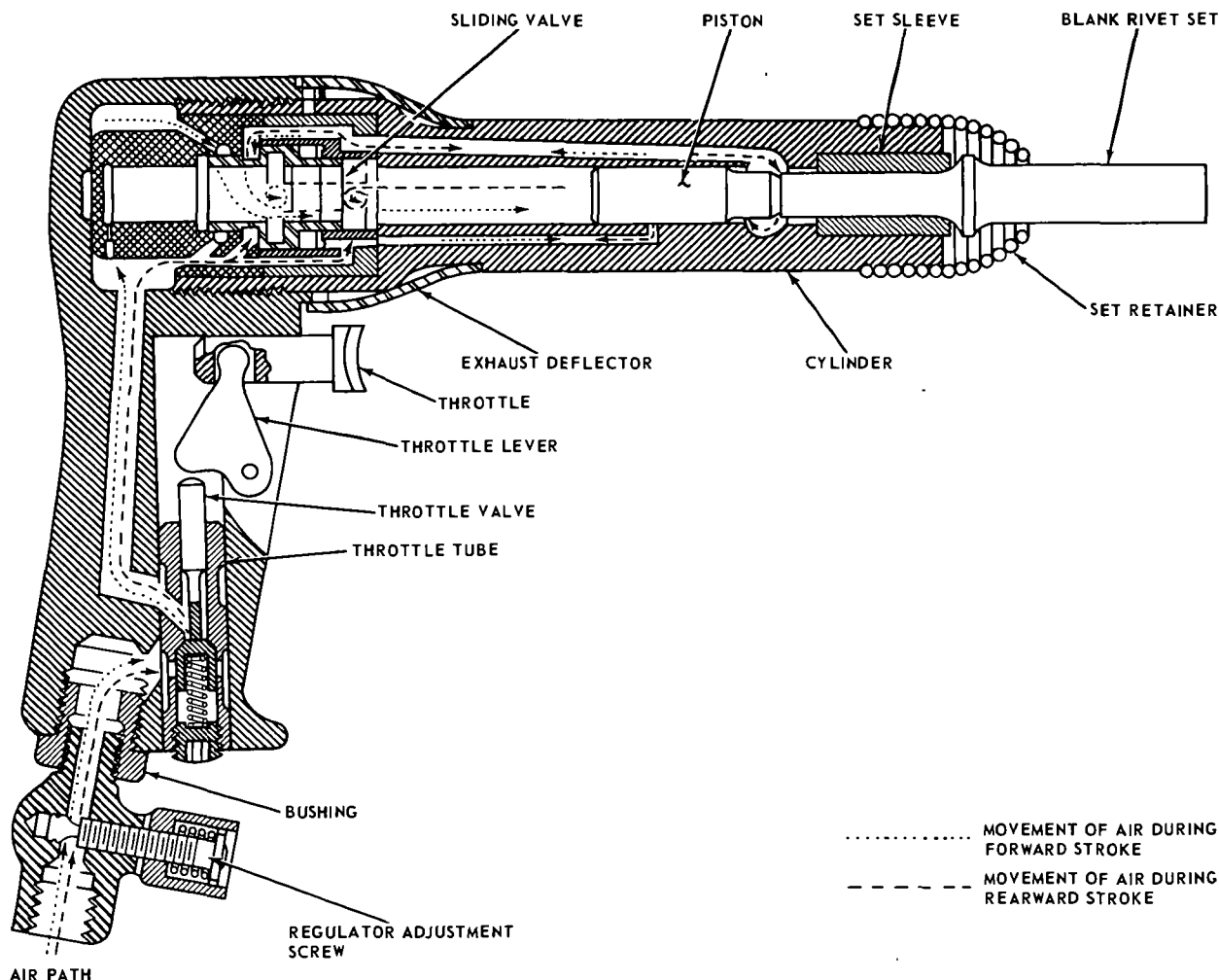


Figure 152. Rivet gun nomenclature.

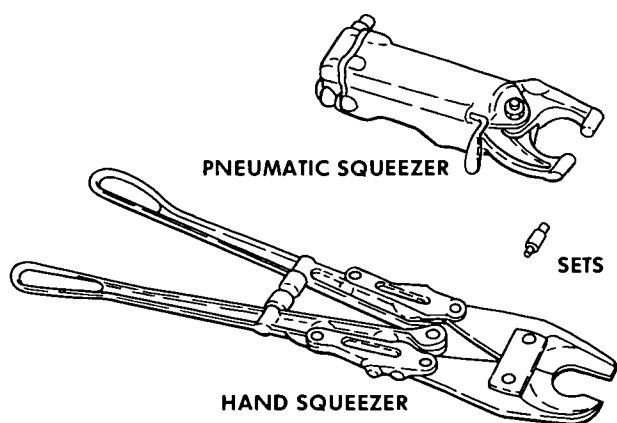


Figure 153. Rivet squeezers.

justments should always be made on scrap material. When correctly adjusted, the microshaver will leave a small round dot about the size of a pinhead on the microshaved rivet.

b. Riveting Procedures.

(1) *Preparation of material.* After the proper rivets have been selected, the process of riveting begins with drilling the rivet holes. It is very important that the rivet holes be of the correct size and shape and free from burrs. If the holes are too small, the protective coating will be scratched from the rivets when the rivets are driven through the holes. If the holes are too large, the rivets will not fill them completely when they are bucked, the joints will not develop their full strength, and structural failure may occur. If countersinking is required, consider the thickness of the metal and adopt the countersinking method recommended in (b) below, for that thickness. If dimpling is required, keep hammer blows or dimpling pressures to a minimum so that no undue work-hardening occurs in the surrounding area.

(a) *Drilling.* To make a rivet hole of the correct size, first drill a hole slightly undersize. This is known as *predrilling* and the hole is called a *pilot hole*. Ream the pilot hole with a twist drill of the correct size selected from table 31. The recommended clearance for rivet holes is 0.002 to 0.004 inch. For hard metals, select a twist drill having an included angle of 118° and turn it at low speeds; but for soft metals, use a twist drill having an included angle of 90° and turn it at higher speeds. Thin sheets of aluminum alloys are drilled with greater accuracy by a drill having an included angle of 118° because the larger angle of the drill has less tendency to tear or elongate the hole. Center punch locations for rivet holes before beginning the actual drill-

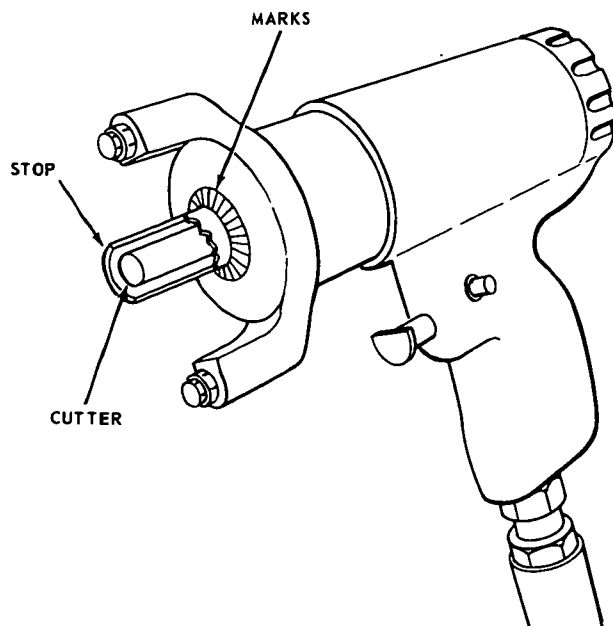


Figure 154. Microshaver.

ing. The center punch mark acts as a guide and lets the drill grip or bite into the metal with greater ease. Make the center punch mark large enough to prevent the drill from slipping out of position, but punch lightly enough so as not to dent the surrounding material. Hold a hard, smooth, wooden backing block securely in position behind the hole locations when drilling. Remove all burrs with a bur remover before riveting.

(b) *Countersinking and dimpling.* The two methods of countersinking commonly used for flush riveting in aircraft construction and repair are the machine or drill countersinking, and dimpling or press countersinking. The proper method for any particular application depends on the thickness of the parts to be riveted, the height and angle of the countersunk head, the tools available, and accessibility. General recommendations for selecting a method are given in table 32. Figure 155 illustrates general rules for countersinking. In the left example, note that the

Table 31. Pilot and Reaming Twist Drill Sizes

Rivet Diameter (In.)	Pilot Size (In.)	Ream Size (In.)
$\frac{3}{32}$	$\frac{3}{32}$ (0.0937)	41 (0.096)
$\frac{1}{8}$	$\frac{1}{8}$ (0.125)	30 (0.1285)
$\frac{5}{32}$	$\frac{3}{32}$ (0.1562)	21 (0.159)
$\frac{3}{16}$	$\frac{3}{16}$ (0.1875)	11 (0.191)
$\frac{1}{4}$	$\frac{1}{4}$ (0.250) *	F (0.257)
$\frac{5}{16}$	$\frac{5}{16}$ (0.3125)	O (0.316)
$\frac{3}{8}$	$\frac{3}{8}$ (0.375)	V (0.377)

* Note that ream size exceeds the maximum tolerance of 0.004 inch. This is permissible only if the next larger drill size happens to be so much larger than the tolerance of 0.004 inch.

Table 32. Countersinking Methods

Diameter of rivet (in.)	Top sheet thickness (in.)	Under sheet thickness (in.)	Use countersink method
$\frac{3}{32}$	0.032 or greater 0.025 or less 0.025 or less	0.051 or greater 0.040 or less	a b c
$\frac{1}{8}$	0.040 or greater 0.032 or less 0.032 or less	0.064 or greater 0.051 or less	a b c
$\frac{5}{32}$	0.051 or greater 0.040 or less 0.040 or less	0.072 or greater 0.064 or less	a b c
$\frac{3}{16}$	0.064 or greater 0.051 or less 0.051 or less	0.091 or greater 0.081 or less	a b c

a Machine countersink (cut) top sheet.

b Press countersink (dimple) top sheet, and machine countersink under sheet(s).

c Press countersink (dimple) top and under sheets.

material is quite thick and that the head of the countersunk rivet extends only about halfway through the upper layer of metal. Countersinking will leave plenty of material for gripping; buckling of the material is out of the question. In the middle example, the countersunk head reaches completely through the upper layer. This condition is permissible but is not recommended. In the right example, the head extends well into the second layer of material. This indicates that the material is thin and that most of it would be ground away by drill countersinking; therefore, dimpling is preferred. Dimpling will work best if the material is not over 0.040 inch thick.

1. *Machine or drill countersinking.* Machine or drill countersinking is accomplished by a suitable cutting tool, machined to the desired angle, which cuts away the edge of the hole so that the countersunk head rivet fits snugly into the recess. The resulting recess is referred to as the *well* or *nest*. When countersinking is required, drill the rivet hole with a pilot drill as recommended in table 31. The limits within which the head of the rivet may extend either above or below the surface of the metal are 0.006 inch in most cases. Therefore, perform the

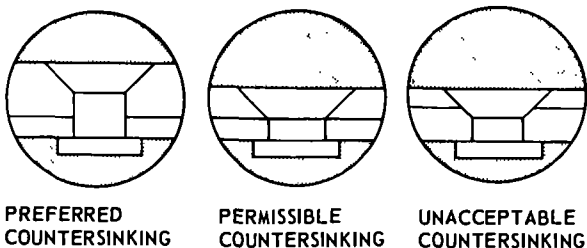


Figure 155. Countersinking.

countersinking accurately, using equipment which is capable of producing results within the specified tolerance. Hold the countersinking tool firmly at right angles to the material. Do not tip it. Tipping elongates the well and prevents the countersunk rivet head from fitting properly. Oversized rivet holes, undersized countersink pilots (in the case of the stop countersink), chattering caused by improper use of the countersink or by a countersink in poor condition, and a countersink not running true in the chuck of the drill are causes of elongated wells.

2. Press countersinking or dimpling.

Press countersinking or dimpling can be accomplished by either of two methods. The male and female die sets may be used, or the rivet may be used as the male die and the draw die as the female die. In either case, the metal immediately surrounding the rivet hole is pressed to the proper shape to fit the rivet head. The depression thus formed, as in machine countersinking, is known as the *well* or *nest*. The rivet must fit the well snugly in order to obtain maximum strength. The number of sheets which can be dimpled simultaneously is limited by the capacity of the equipment used. When dimpling a hole, rest the female die on some solid surface, place the material on the female die, insert the male die in the hole to be dimpled, and then hammer the male die. Strike with several solid blows until the dimple is formed. In die dimpling, the pilot hole of the female die should be smaller than the diameter of the rivet to be used. Therefore, the rivet hole must be reamed to the exact diameter after the dimpling operation has been completed so that the rivet fits snugly. When using a countersunk rivet as the male dimpling die, place the female die in the usual position and back it with a bucking bar. Place the rivet of the required type into the hole and strike the rivet with a pneumatic riveting hammer. This method of countersinking is often called *coin pressing*. It should be used only when the regular male die is not available.

Note. Coin pressing has a distinct disadvantage in that the rivet hole must be drilled to correct rivet size before the dimpling operation is accomplished. Since metal stretches during the dimpling operation, the hole becomes enlarged and the rivet must be swelled slightly before driving to produce a close fit. Because the rivet head will cause slight distortions in the recess (and these are characteristic only to that particular rivet head), it is wise to drive the same rivet that was used as the male die during the dimpling process. Do not substitute another rivet, either of the same size or a size larger.

3. *Thermodimpling.* Thermodimpling consists of two processes, radius dimpling and coin dimpling. The major difference between radius and coin dimpling is in the construction of

the female die. In radius dimpling a solid female die is used. Coin dimpling uses a sliding ram female die (fig. 150). It is this sliding coining ram that makes the coin dimpling process superior. During the coin dimpling process, the metal is coined (made to flow) into the contours of the dies so that the dimple assumes the true shape of the die. The pressure exerted by the coining ram prevents the metal from compressing and thereby assures uniform cross-sectional thickness of the sides of the dimple and a true conical shape. Coin dimpling offers several advantages. It improves the configuration of the dimple, produces a more satisfactory aerodynamic skin surface, eliminates radial and circumferential cracking, insures a stronger and safer joint, and allows identical dies to be used for both skin and under-structure dimpling.

(2) *Driving of rivets.* Selection of the appropriate bucking bar is one of the most important factors in bucking rivets. If the bar does not have the correct shape it will deform the rivet head; if the bar is too light, it will not give the necessary bucking weight, and the material may become bulged toward the shop head; and, if the bar is too heavy, weight and the bucking force may cause the material to bulge away from the shop head. Recommended weights of bucking bars to be used with various rivet sizes are given in table 33.

Table 33. Recommended Bucking Bar Weights

Rivet diameter (in.)	Approximate weight (lb)
$\frac{3}{32}$	2 to 3
$\frac{1}{8}$	3 to 4
$\frac{5}{32}$	3 to $4\frac{1}{2}$
$\frac{3}{16}$	4 to 5
$\frac{1}{4}$	5 to $6\frac{1}{2}$

(a) *Hand method.* Either of two methods may be used when hand riveting, depending upon the location and accessibility of the work. In one method, the rivet is driven from the head end with a hand set and hammer and bucked from the shank end. In the other method, the rivet is driven from the shank end with a hand set and hammer, and bucked from the head with a hand set held in a vise or a bottle bar (a special bucking bar recessed to hold a rivet set). The latter method is known as *reverse riveting* and is commonly used in hand riveting but is not considered good practice in pneumatic riveting. When using either of the described methods, keep hammer strokes to a minimum. Too much hammering will change the crystalline structure

of the rivet or the material around it, causing the joint to lose some of its strength. Hold the bucking bar and rivet set square with the rivet at all times. Misuse of the rivet set and bucking bar will result in marring or scratching the rivet head or material, and may cause undue corrosion, which will weaken the structure of the aircraft. The diameter of a correctly formed shop head should be $1\frac{1}{2}$ diameters of the rivet shank and the height should be about $\frac{1}{2}$ diameter.

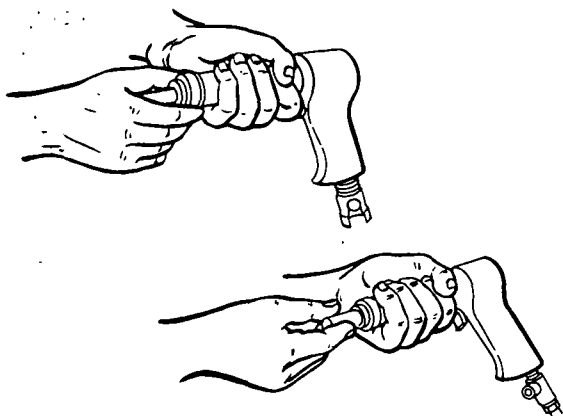
(b) *Pneumatic method.* In pneumatic riveting the pressure for bucking the rivet is applied with a rivet set and a pneumatic rivet gun. When using a pneumatic rivet gun, hold rivet gun and bucking bar at right angles to work and exert sufficient pressure to prevent the bucking bar from jumping off. Figure 156 illustrates typical riveting procedures using a pneumatic rivet gun. If a long line of rivets are to be driven, time can be saved if several rivets are inserted in the holes and held in place by a strip of masking tape over their heads. The rivet gun may be placed on the rivet without removing the tape, thus the tape serves the double duty of holding the rivets in place and forming a cushion to prevent a rivet set from damaging the material.

Warning: Exercise care when using a pneumatic rivet gun. If a rivet set is placed in a pneumatic rivet gun without a set retainer and the throttle of the rivet gun is open, the rivet set may be projected like a bullet out of the gun and cause either severe injury to a person or damage to equipment.

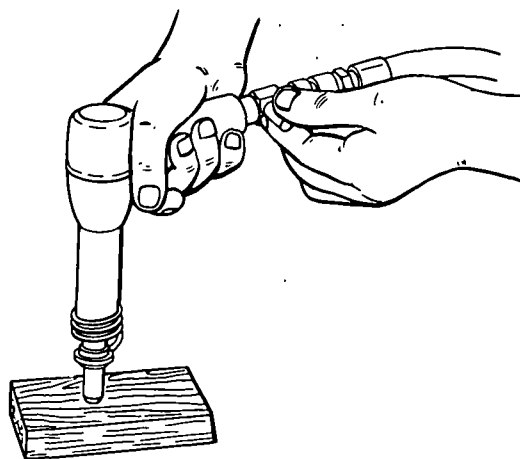
(c) *Squeeze method.* Although the squeeze method of riveting is limited to edges of sheets or assemblies, it produces the most uniform and balanced type of head; each rivet is upset in a single operation; all rivets are headed over with uniform pressure; and each rivet shank is uniformly expanded to completely fill each rivet hole. Riveting with a squeezer is a quick method and requires only one operator. To install rivets using a squeezer, select and insert suitable end sets to match the rivet being used; place stationary jaw of squeezer on head of rivet, and using movable jaw, upset shank of rivet.

103. Rivet Inspection

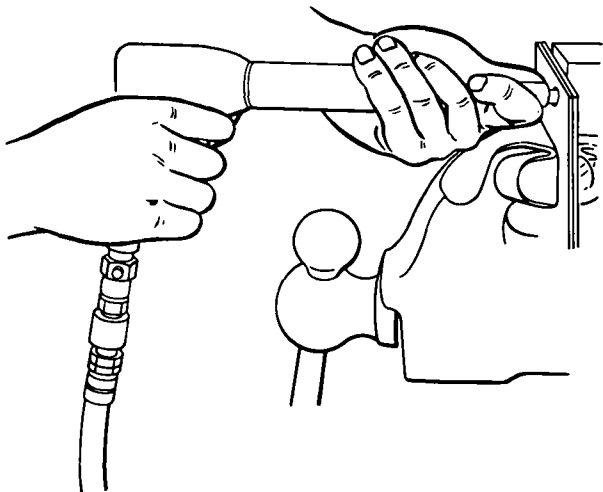
a. *Types of Rivet Failures.* Generally, the design of riveted joints is based on the theory that the total joint strength is the sum of the individual strengths of a group of rivets. It is then obvious that, if any one rivet fails, its load must immediately be carried by others of the group; if they are unable to carry this added load, progressive joint failure then occurs. Stress concentrations will usually cause one rivet to fail first. Careful analysis of such a rivet in a joint will



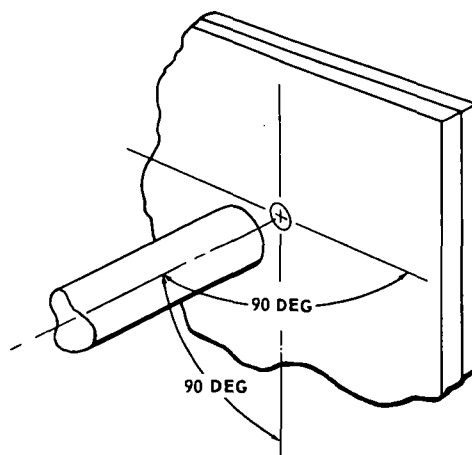
1. INSTALLING RIVET SET



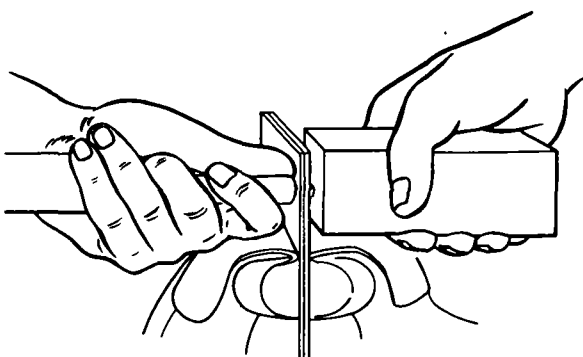
2. ADJUSTING SPEED OF THE GUN



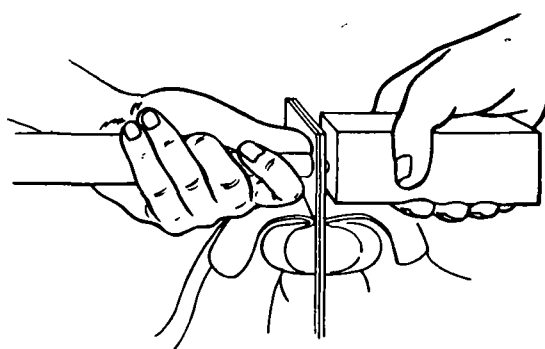
3. HOLDING GUN AND SET



4. POSITION OF THE SET



5. POSITION OF THE GUN,
SET, AND BUCKING BAR



6. UPSETTING THE RIVET

Figure 156. Riveting procedures using a pneumatic rivet gun.

indicate that it has been too highly loaded, with the possibility that neighboring rivets may have partially failed. Underload rivets are subject to

three types of failures, shear, bearing, and head failure.

(1) *Shear failure.* Shear failure is perhaps

the most common of rivet failures. It is a breakdown of the rivet shank by forces acting along the plane of two adjacent sheets, causing a slipping action which may be severe enough to break the rivet shank in two. If the shank becomes loaded beyond the yield point of the material and remains overloaded, a permanent shift is established in the sheets and the rivet shank may become joggled.

(2) *Bearing failure.* If the rivet is excessively strong in shear, bearing failure occurs in the sheet at the edge of the rivet hole. The application of large rivets in thin sheets brings about such a failure. In that case, the sheet is locally crushed or buckled, and the buckling destroys the rigidity of the joint. Vibrations, set up by engine operation or by air currents in flight, may cause the buckled portion to flutter and the material to break off close to the rivet head. If buckling occurs at the end of the sheet, a tear-out may result. In either case, replacement of the sheet is necessary.

(3) *Head failure.* Head failure may result from complex loadings occurring at a joint, causing stresses of tension to be applied to the rivet head. The head may fail by shearing through the area corresponding to the rivet shank or, in thicker sheets, may fail through a prying action which causes failure of the head itself. Any visible head distortion is cause for replacement.

b. *Inspection Procedure.* Inspection consists of examining both the shop and manufactured heads and the surrounding skin and structural parts for deformities. A straight-edge or rivet gage as shown in figure 157 can be used to check

the condition of the upset rivet head. Deformities in the manufactured head of universal-head rivets may be detected visually. On countersunk-head rivets a straightedge may be used as shown in figure 157.

(1) During the repair of an aircraft structural part, examine adjacent parts to determine the condition of neighboring rivets. The presence of chipped or cracked paint around the heads may indicate shifted or loose rivets. If the heads are tipped or if rivets are loose, they will show up in groups of several consecutive rivets and will probably be tipped in the same direction. If heads which appear to be tipped are not in groups and are not tipped in the same direction, tipping may have occurred during some previous installation.

(2) Inspect rivets which are known to have been critically loaded, but which show no visible distortion, by drilling off the head and carefully punching out the shank. If upon examination the shank appears joggled and the holes in the sheet misaligned, the rivet has failed in shear. In that case, determine what is causing the shearing stress and take the necessary corrective action. Countersunk rivets that show head slippage within the countersink or dimple, indicating either sheet bearing failure or rivet shear failure, must be replaced.

(3) Joggles in removed rivet shanks indicate partial shear failure. Replace these rivets with the next larger size. Also, if the rivet holes show elongation, replace the rivets with the next larger size. Sheet failures (such as tearouts, cracks between rivets, and the like) usually indicate damaged rivets, and the complete repair of the joint may require replacement of the rivets with the next larger size.

Note. The general practice of replacing a rivet with the next larger size ($\frac{1}{32}$ -inch greater diameter) is necessary to obtain the proper joint strength of rivet and sheet when the original rivet hole is enlarged. If the rivet in an elongated hole is replaced by a rivet of the same size, its ability to carry its share of the shear load is impaired and joint weakness results.

104. Rivet Removal Procedures

When removing a rivet for replacement, exercise care so that the rivet hole will retain its original size and shape and replacement with the next larger size will not be necessary. If the rivet is not removed properly, the strength of the joint may be weakened. Hand tools, power tools, or a combination of both may be used to remove rivets.

a. Removal of Protruding Head Rivets.

(1) File a flat area on the manufactured head of protruding head rivets and center punch the flat surface.

Note. On thin metal, back up the rivet on the upset head when center punching to avoid depressing the metal.

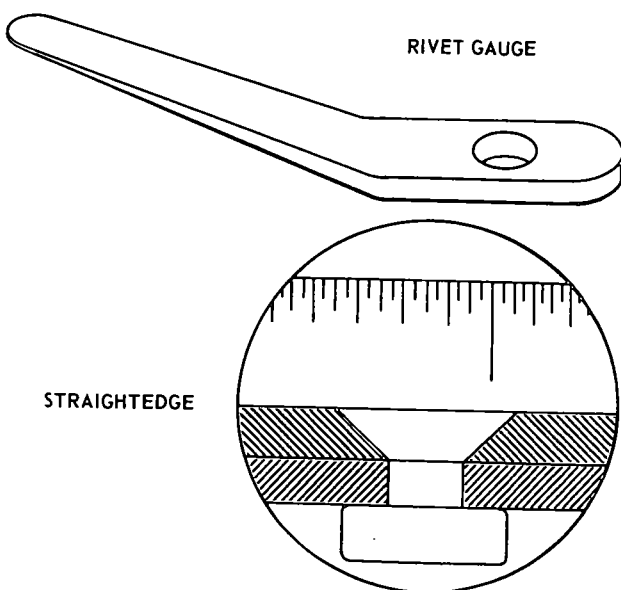


Figure 157. Tools used to gage rivets.

(2) Using a drill one size smaller than the rivet shank, drill through the rivet head. Be careful not to drill too deep, as the rivet shank will turn with the drill and cause a tear.

(3) Insert a drift punch diagonally into the drilled hole and knock the head off by lightly striking the drift punch.

(4) Drive out the shank of rivet with a drift punch slightly smaller than the diameter of the shank. On thin metal or unsupported structures, support the sheet with a bucking bar while driving out the shank. If the shank is exceptionally tight after the rivet head is removed, drill

the rivet about two-thirds of the way through the thickness of the material and then drive out the remainder of the rivet with a drift punch.

b. *Removal of Countersunk-Head Rivets.* If the manufactured head on countersunk rivets is accessible and has been formed over heavy material such as an extruded member, the head can be drilled through and sheared off as described above. If the material is thin, drill through the shank of the rivet and then cut the formed head off with diagonal cutting pliers. The remainder of the rivet may then be driven out from the inside with a drift punch.

Section III. SPECIAL RIVETS

105. General

Special rivets are designed for riveting in places where access to both sides of a riveted structure or structural part is impossible, or where limited space will not permit the use of a bucking bar. Special rivets are manufactured by several manufacturers and have unique characteristics that require special installation tools, special installation procedures, and special removal procedures. Because these rivets are often installed in locations where one head (usually the shop head) cannot be seen, they are also called *blind* rivets. Mechanically expanded rivets, rivnuts, and Hi-shear rivets are three types of special rivets used on Army aircraft discussed in this chapter.

106. Mechanically Expanded Rivets

a. *Self-Plugging (Friction Lock) Rivets.*

(1) *Description.* Self-plugging (friction lock) rivets are fabricated in two parts, a rivet head with a hollow shank or sleeve, and a stem that extends through the hollow shank. Two common head styles are available, a protruding head and a 100-degree countersunk head. The stem may have a knob on the upper portion or it may have a serrated portion as shown in figures 158 and 159.

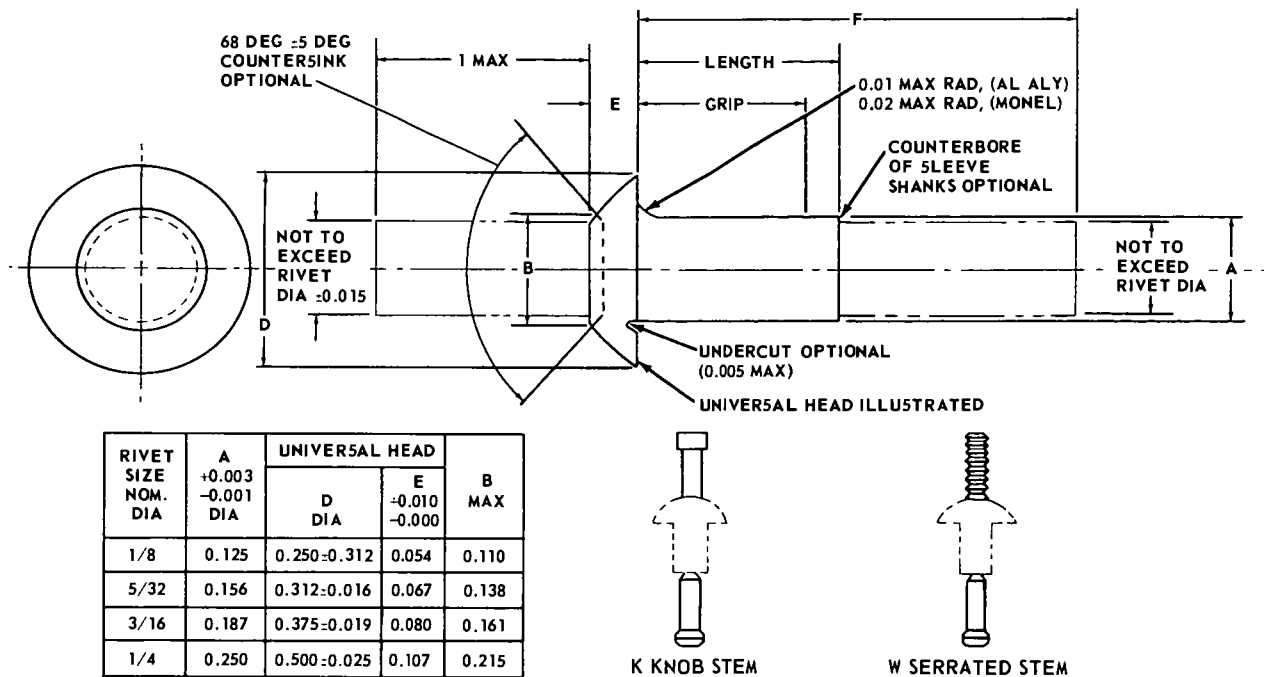
(2) *Composition.* Self-plugging (friction lock) rivets are available in 2117 and 5056 aluminum alloy and nickel-copper alloy (monel).

(3) *Uses.* Self-locking (friction lock) rivets are shear-type fasteners and will not be used where appreciable tensile loads on the rivets will exist, such as control surface hinge brackets, wing attachment fittings, landing gear fittings, fixed tail surface attachment fittings, or in other similar heavily stressed locations. Also, they will not be used in hulls, floats, or tanks where a gas-tight joint is required. Because it is not necessary to have access to the opposite side of the work, self-plugging (friction lock) rivets can be used to attach assemblies to hollow tubes,

corrugated sheet, hollow boxes, etc. Since a hammering force is not necessary to install the rivet, it can be used to attach assemblies to plywood or plastics.

(4) *Selection.* Factors to consider in the selection of the correct rivet for installation are: installation location, composition of the material being riveted, thickness of the material being riveted, and strength desired. If the rivet is to be installed on an aerodynamically smooth surface, or clearance for an assembly is needed, flush-head rivets should be selected. In other areas where clearance of smoothness is not a factor, the protruding-head type rivet may be utilized. Material composition of the rivet will depend upon the type of material being riveted. Aluminum alloy 2117 rivets can be used on most aluminum alloys. Aluminum alloy 5056 rivets should be used when the material being riveted is magnesium. Monel rivets should always be selected for riveting assemblies fabricated from steel. The thickness of the material being riveted determines the overall length of the shank of the rivet. As a general rule, the shank of the rivet should extend beyond the material thickness approximately $3/64$ inch to $1/8$ inch before the stem is pulled (fig. 160).

(5) *Installation tools.* The tools to install self-plugging (friction lock) rivets depend upon the manufacturer of the rivet being installed. Each company has designed special tools which should always be used to insure satisfactory results with their product. Hand tools as well as pneumatic tools are available. Standard twist drills for drilling holes can be used. Both manually operated and power operated guns are manufactured for pulling the stem of the rivet as shown in figure 161. Nomenclature for the various tools and assemblies available depend upon the manufacturer. Application and use of the equipment is basically the same. Whether called a hand tool, air tool, hand gun, or pneumatic gun,

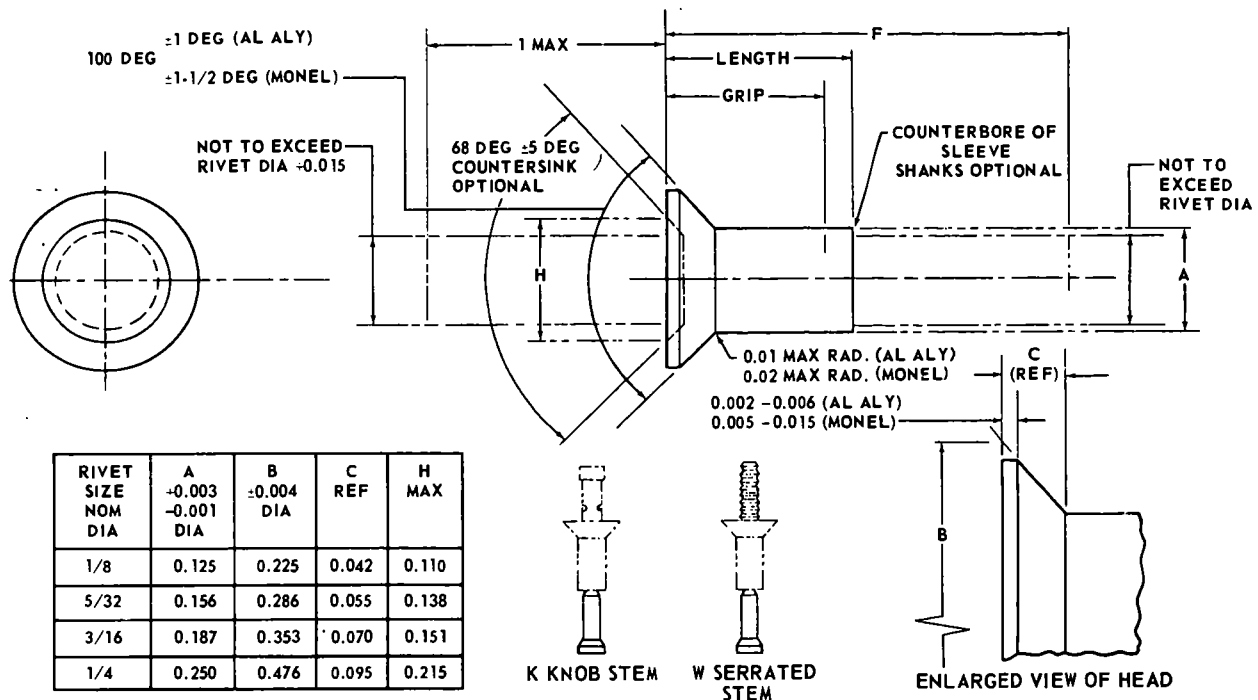


1/8 RIVET DIAMETER, NOMINAL				5/32 RIVET DIAMETER, NOMINAL				3/16 RIVET DIAMETER, NOMINAL				1/4 RIVET DIAMETER, NOMINAL			
GRIP RANGE		LENGTH MAX	F MAX	GRIP RANGE		LENGTH MAX	F MAX	GRIP RANGE		LENGTH MAX	F MAX	GRIP RANGE		LENGTH MAX	F MAX
MIN	MAX			MIN	MAX			MIN	MAX			MIN	MAX		
UP TO	0.062	0.170	0.500	UP TO	0.062	0.192	0.558	UP TO	0.062	0.215	0.638	0.125	0.187	0.385	0.970
0.063	0.125	0.232	0.600	0.063	0.125	0.254	0.620	0.063	0.125	0.277	0.700	0.188	0.250	0.447	1.090
0.126	0.187	0.295	0.750	0.126	0.187	0.317	0.808	0.126	0.187	0.340	0.888	0.251	0.312	0.510	1.220
0.188	0.250	0.357	0.850	0.188	0.250	0.379	0.870	0.188	0.250	0.402	0.950	0.313	0.375	0.572	1.340
0.251	0.312	0.420	1.010	0.251	0.312	0.441	1.058	0.251	0.312	0.465	1.138	0.376	0.437	0.635	1.470
0.313	0.375	0.482	1.100	0.313	0.375	0.503	1.120	0.313	0.375	0.527	1.200	0.438	0.500	0.697	1.590
				0.376	0.437	0.567	1.339	0.376	0.437	0.590	1.419	0.501	0.562	0.760	1.720
				0.438	0.500	0.629	1.401	0.438	0.500	0.652	1.481	0.563	0.625	0.832	1.840
								0.501	0.562	0.715	1.637	0.626	0.687	0.885	1.970
								0.563	0.625	0.777	1.699	0.688	0.750	0.947	2.090
								0.626	0.687	0.840	1.887	0.751	0.812	1.010	2.220
								0.688	0.750	0.902	1.949	0.813	0.875	1.072	2.340

NOTES:

1. ADD AD IN PLACE OF DA5H TO INDICATE ALUMINUM ALLOY, COMPOSITION 2117.
2. ADD B IN PLACE OF DA5H TO INDICATE ALUMINUM ALLOY, COMPOSITION 5056.
3. ADD M IN PLACE OF DA5H TO INDICATE NICKEL-COPPER ALLOY (MONEL).
4. ADD P AFTER MATERIAL DESIGNATION TO INDICATE CADMIUM PLATE.
5. ADD IDENTIFICATION CODE LETTERS AFTER DA5H NUMBER TO INDICATE TYPE OF RIVET BASED ON METHOD OF INSTALLATION.
6. ADD K TO INDICATE KNOB STEM RIVET.
7. ADD W TO INDICATE SERRATED STEM RIVET.
8. NO LETTER INDICATES A COMPLETE RIVET WITH TYPE OF STEM OPTIONAL.
9. EXAMPLES OF PART NUMBERS:
M520600DAD5-5 RIVET, 2117 ALUMINUM ALLOY SLEEVE, 0.156-INCH DIA, TYPE OF STEM OPTIONAL, 0.251-TO 0.312-INCH GRIP RANGE.
M520600B5K5 - RIVET, 5056 ALUMINUM ALLOY SLEEVE, 0.156-INCH DIA, KNOB STEM, 0.251-TO 0.312-INCH GRIP RANGE.
M520600M5W5 - RIVET, NICKEL-COPPER ALLOY (MONEL) SLEEVE, 0.156-INCH DIA, SERRATED STEM, 0.251-TO 0.312-INCH GRIP RANGE.
M520600MP5W5 - RIVET, NICKEL-COPPER ALLOY (MONEL) SLEEVE, CADMIUM PLATED, 0.156-INCH DIA, SERRATED STEM, 0.251-TO 0.312-INCH GRIP RANGE.
10. DIMENSIONS SHOWN ARE IN INCHES.

Figure 158. MS20600 rivet identification (protruding head).

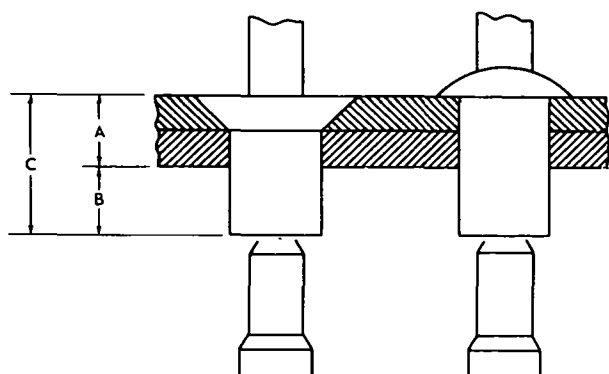


3/32 RIVET DIAMETER, NOMINAL				1/8 RIVET DIAMETER, NOMINAL				3/16 RIVET DIAMETER, NOMINAL				1/4 RIVET DIAMETER, NOMINAL			
GRIP RANGE		LENGTH MAX	F MAX	GRIP RANGE		LENGTH MAX	F MAX	GRIP RANGE		LENGTH MAX	F MAX	GRIP RANGE		LENGTH MAX	F MAX
MIN	MAX			MIN	MAX			MIN	MAX			MIN	MAX		
0.065	0.125	0.254	0.620	UP TO	0.062	0.170	0.500	0.080	0.125	0.277	0.700	0.125	0.187	0.385	0.968
0.126	0.187	0.317	0.808	0.063	0.125	0.232	0.562	0.126	0.187	0.340	0.888	0.188	0.250	0.447	1.030
0.188	0.250	0.379	0.870	0.126	0.187	0.295	0.750	0.188	0.250	0.402	0.950	0.251	0.312	0.510	1.218
0.251	0.312	0.441	1.058	0.188	0.250	0.357	0.812	0.251	0.312	0.465	1.138	0.313	0.375	0.572	1.280
0.313	0.375	0.503	1.120	0.251	0.312	0.420	1.010	0.313	0.375	0.527	1.200	0.376	0.437	0.635	1.468
0.376	0.437	0.567	1.339	0.313	0.375	0.482	1.072	0.376	0.437	0.590	1.419	0.438	0.500	0.697	1.530
0.438	0.500	0.629	1.401					0.438	0.500	0.652	1.481	0.501	0.562	0.760	1.718
								0.501	0.562	0.715	1.637	0.563	0.625	0.822	1.780
								0.563	0.625	0.777	1.699	0.626	0.687	0.885	1.968
								0.626	0.687	0.840	1.887	0.688	0.750	0.947	2.030
								0.688	0.750	0.902	1.949	0.751	0.812	1.010	2.218
												0.813	0.875	1.072	2.280

NOTES:

1. ADD AD IN PLACE OF DASH TO INDICATE ALUMINUM ALLOY, COMPOSITION 2117.
2. ADD B IN PLACE OF DASH TO INDICATE ALUMINUM ALLOY, COMPOSITION 5056.
3. ADD M IN PLACE OF DASH TO INDICATE NICKEL-COPPER-ALLOY (MONEL).
4. ADD P AFTER MATERIAL DESIGNATION TO INDICATE CADMIUM PLATE.
5. RIVET STEM IDENTIFICATION CODE LETTERS MAY BE ADDED AFTER THE DASH NUMBER TO SPECIFY THE TYPE OF RIVET STEM BASED ON METHOD OF INSTALLATION.
6. ADD K TO INDICATE KNOB STEM RIVET.
7. ADD W TO INDICATE SERRATED STEM RIVET.
8. NO LETTER INDICATES A COMPLETE RIVET WITH TYPE OF STEM OPTIONAL.
9. EXAMPLES OF PART NUMBERS:
MS20601AD5-5 - RIVET, 2117 ALUMINUM ALLOY SLEEVE, 0.156-INCH DIA, TYPE OF STEM OPTIONAL, 0.251-TO 0.312-INCH GRIP RANGE.
MS20601B5K5 - RIVET, 5056, ALUMINUM ALLOY SLEEVE, 0.156-INCH DIA, KNOB STEM, 0.251-TO 0.312-INCH GRIP RANGE.
MS20601M5W5 - RIVET, NICKEL-COPPER-ALLOY (MONEL) SLEEVE, 0.156-INCH DIA, SERRATED STEM, 0.25-1TO 0.312-INCH GRIP RANGE.
MS20601MP5W5 - RIVET, NICKEL-COPPER-ALLOY (MONEL) SLEEVE, CADMIUM PLATED, 0.156-INCH DIA, SERRATED STEM, 0.251-TO 0.312-INCH GRIP RANGE.
10. DIMENSIONS SHOWN ARE IN INCHES.

Figure 159. MS20601 rivet identification (flush head).



A - THICKNESS OF MATERIAL (GRIP RANGE)
B - 3/64 TO 1/8 INCH
C - TOTAL RIVET SHANK LENGTH

Figure 160. Determining rivet length.

all of these used with but one goal—the proper installation of a rivet. The portion of the tool or gun that is of prime importance to the air-frame repairman is the part that is placed on the rivet. Whether called a nose assembly or sleeve and drawbolt, the user should always assure himself that the same size as the rivet shank diameter is selected. Pneumatic tools operate on the same air pressure as pneumatic riveting hammers, 90 to 100 psi. Follow the operational procedures and adjustments recommended by the manufacturer.

(6) *Installation procedures.* The installation of self-plugging (friction lock) rivets is basically the same as that for common solid shank rivets, described in section II. The following procedures are typical for installing self-plugging (friction lock) rivets:

(a) Select rivet to be installed as outlined in (4) above.

(b) Determine hole size from table 34 and drill holes.

(c) Position gun selected on the stem of the rivet. Gun selected is determined by the shank diameter of the rivet, manufacturer of the rivet, and number of rivets to be installed.

(d) Apply pulling force to the stem of the rivet until the stem snaps.

(e) Check the installation of the rivet by applying approximately 15 pounds of pressure to the end of the stem.

(f) Trim the stem flush with the head of the rivet with a pair of diagonal pliers ground smooth on the cutting side.

(7) *Inspection.* Often the only inspection than can be made on self-plugging (friction lock) rivets is on the head of the rivet. The head of the rivet should fit tightly against the metal. The stem of the rivet should be trimmed flush

Table 34. Hole and Drill Sizes for Self-Plugging (Friction Lock) Rivets

Rivet dia (in.)	Hole size (in.)	Dimension size
1/8	0.129–0.132	30
5/32	0.160–0.164	20
3/16	0.192–0.196	10
1/4	0.256–0.261	F

with the head of the rivet whether it is a protruding head or countersunk head.

(8) *Removal procedures.* Self-plugging (friction lock) rivets are removed in the same manner as solid shank rivets described in section II, except for the preliminary step of driving out the stem. The following steps should be used in their proper sequence:

(a) Punch out the rivet stem with a pin punch.

(b) Drill out the rivet head, using a drill the same size as the rivet shank.

(c) Pry off the weakened rivet head with a pin punch.

(d) Push out the remainder of the rivet shank with a punch. If the shank will not push out, drill the shank, taking care not to enlarge the hole in the material.

b. *Self-Plugging (Mechanical Lock) Rivets.*

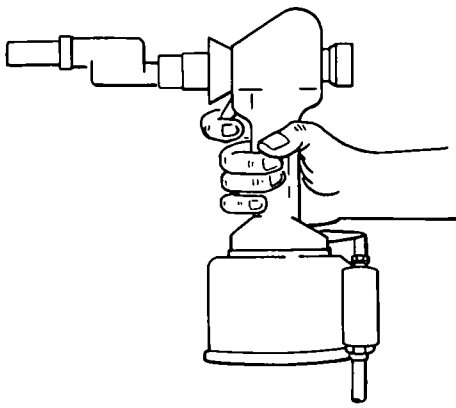
(1) *Description.* Self-plugging (mechanical lock) rivets are manufactured by Huck Manufacturing Company and the Cherry Rivet Division, and are fabricated in two parts, a hollow sleeve and a pin. The hollow sleeve had a head, either brazier or countersunk, with a conical recess and locking collar. The pin has an extruded angle and land to expand the sleeve for hole filling, a breakneck groove, a locking groove, and a head. The pull grooves on the protruding end of the pin fit the jaws of the rivet tool. The mechanical lock between the pin and sleeve gives substantially the strength equivalent to common solid shank rivets.

(2) *Composition.* The hollow sleeve of self-plugging (mechanical lock) rivets is fabricated from 5056–H14 aluminum alloy. The pin is fabricated from 2024–T36 aluminum alloy.

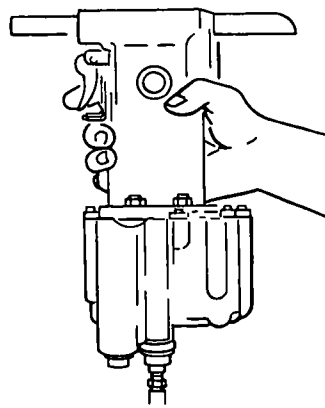
(3) *Uses.* Self-plugging (mechanical lock) rivets can be used in the same applications as the friction-lock type described in a above. In addition, mechanical lock rivets can be substituted for common solid-shank rivets in almost all cases.

(4) *Selection.* General requirements for selection of mechanical lock rivets are the same as for friction lock rivets as described in a above. 2024–T36 aluminum alloy rivets should be used in most aluminum alloys, and 5056–H14 aluminum alloy rivets should be used in magnesium.

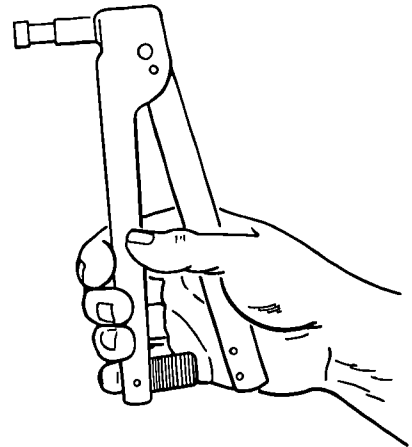
HUCK RIVET GUNS



139-A AIR TOOL

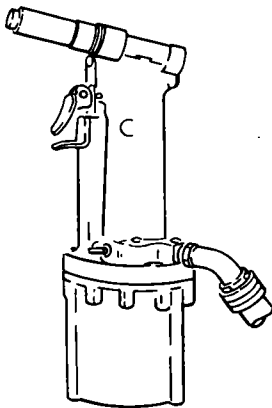


352 AIR TOOL

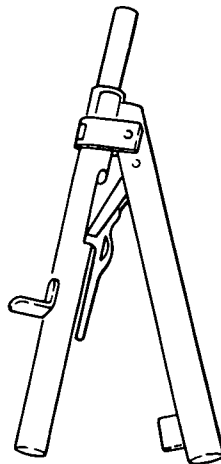


120 HAND TOOL

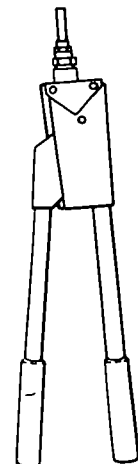
CHERRY RIVET GUNS



G15RB & G15RC
PNEUMATIC GUN
(USES G6H SERIES
PULLING HEADS)



G36 HAND GUN
(USES G6H SERIES
PULLING HEADS)



G11 HAND GUN
(USES G6H SERIES
PULLING HEADS)

Figure 161. Self-plugging (friction lock) rivet guns.

The length of the selected rivet shank is determined by the thickness of the material (grip range) being riveted.

(5) *Installation tools.* Self-plugging (mechanical lock) rivets require special tools, which should be used to install the rivets. The Huck CKL rivet is installed by using the Huck Model CP350 blind rivet pull tool (fig. 162). Cherry rivets are installed using the Cherry Model H-610 pulling head for use with standard power and hand guns (fig. 163). The nose of the CP350 blind rivet pull tool includes: a set of check jaws which fit the serrated grooves on the rivet stem and pull it through the rivet shank to drive the rivet; an outer anvil which bears against the outer portion of the manufactured head during the driving operation; and an inner anvil which

advances automatically to drive the locking collar into position after the blind head is formed. A change in rivet diameter requires a change in chuck jaws, outer anvil and inner thrust bearing, and an adjustment of the shift operating pressure. Adjustment procedures are specified by the manufacturer. If a manual is not available, the following procedures for adjustment of a Model CP350 blind rivet pull tool can be followed.

(a) Remove pipe plug from tool cylinder and connect a pressure gage to the tool.

(b) Press tool trigger and release it the instant a pull of exhaust indicates that the shift valve controlling the inner anvil has shifted. The gage will then indicate the shift pressure. The trigger must be released immedi-

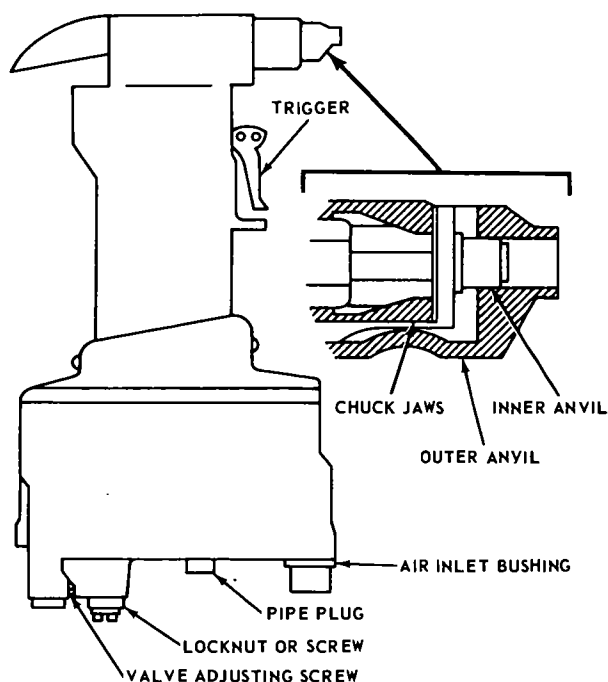


Figure 162. Huck model CP350 blind rivet pull tool.

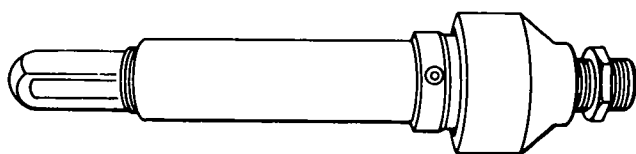


Figure 163. Cherry model H-610 pulling head.

ately as the valve shifts; otherwise, the gage will record the higher pressure which builds up as soon as the valve shifts. (Approximate pressures are shown in table 35.)

Table 35. Model CP350 Operating Pressures

Rivet diameter (in.)	Shift valve operating pressure (psi)
$\frac{1}{8}$	30-31
$\frac{5}{32}$	40-47
$\frac{3}{16}$	66-67

(c) To adjust the pressure, loosen the valve adjusting screw locknut setscrew and turn the valve adjusting screw (clockwise to increase pressure, counterclockwise to decrease pressure) until the desired pressure is obtained. Check the pressure after tightening the valve adjusting screw locknut setscrew. When rivets of extremely long grip range are to be driven, adjust the high pressure limit. For efficient operation of the tool, the minimum desired line pressure should

not be less than 90 psi and the maximum not more than 110 psi.

(6) *Installation procedures.* Procedures used in installing self-plugging (mechanical lock) rivets are basically the same as those used for installing self plugging (friction lock) rivets described in (b) above. Precautions to be observed are—

(a) Be sure the correct grip range is selected.

(b) Always use the correct nose assembly or pulling tool for the diameter rivet selected. (For the Huck rivet, check the tool air pressure for the correct setting.)

(c) When inserting the rivet in the tool and the material, hold a slight pressure against the head of the rivet.

(d) Determine that the rivet is completely driven before lifting the tool from the rivet head. (The pin should snap.)

(e) Check each rivet after the driving sequence has been completed for proper pin breakage. (The rivet pin should snap off even with the head of the rivet.)

(7) *Inspection.* Visual inspection of the seating of the pin in the manufactured head is the most reliable and simplest means of inspection for mechanical lock rivets. If the proper grip range has been used and the locking collar and broken end of the pin are approximately flush with the manufactured head, the rivet has been properly upset and the lock formed. Insufficient grip length is indicated by the pin breaking below surface of the manufactured head. Excessive grip length is indicated by the pin breaking off well above the manufactured head. In either case, the locking collar might not be seated properly, thus forming an unsatisfactory lock.

(8) *Removal procedures.* Remove self-plugging (mechanical lock) rivets as follows:

(a) Shear lock by driving out rivet pin, using a tapered steel drift pin not over $\frac{3}{32}$ inch in diameter at small end.

(b) Pry remainder of locking collar out of rivet head, using drift pin as a pry.

(c) Drill nearly through rivet head, using the same size drill as rivet pin.

(d) Break off head, again using drift pin as a pry.

(e) Drive out remainder of rivet with a pin having a diameter equal to or only slightly less than nominal rivet diameter. An undriven rivet of the same diameter will serve this purpose.

107. Rivnuts

a. *Description.* Rivnuts are internally threaded and counterbored tubular rivets that can be headed blind and are used in locations where

bucking access is impossible, such as attachment of deicing boots to leading edges. Rivnuts are made of 6053 aluminum alloy or steel in two head styles and ends: the flat head with open or closed ends, and the countersunk head with open or closed ends (fig. 164). Each head style is made in sizes of 4-40, 6-32, 8-32, 10-32, 1/4-20, and 5/16-18, which represent the machine screw size of thread inside the Rivnut. Keyed Rivnuts for use as a nut plate are available for the 6-32, 8-32, and 10-32 thread sizes. A Rivnut with a part number ending in a 1 or 6 has a 100-degree countersunk head; a 0 or 5 has a flat head. Letters and numbers used in a Rivnut part number are as follows:

A = Aluminum

S = Steel

First number = Machine screw size of thread

A dash = Open end keyless

B = Closed end keyless

K = Open end with key

KB = Closed end with key

Last number = Maximum grip in thousandths of an inch

b. Uses. Keyed Rivnuts are used as a nut plate. Rivnuts without keys are used for straight blind riveting where no torque loads are imposed. Flat head Rivnuts are used when head thickness will not interfere with the surface contour of the material. If flush installations are required, use countersunk head Rivnuts. Closed end Rivnuts are used when a sealed installation is required.

c. Selection.

(1) The factors to be considered in selecting Rivnuts are material, grip range, style of head, type end, and the presence or absence of a key. Avoid selecting a Rivnut where dissimilar metals will be encountered. Use aluminum alloy Rivnuts for aluminum material and steel for steel material. When selecting head style, apply the same rules as for solid shank rivet applications. Select key type Rivnuts when screws are to be inserted, and use closed end Rivnuts when sealed installations are required.

(2) The most important factor to be considered is the proper grip length. The objective

when installing a Rivnut is to produce an ideal bulge on the blind side of the work without distorting any of the threads inside the Rivnut. Grip is the overall thickness of the material at the hole where the Rivnut is to be installed. For flat head or countersunk head Rivnuts to be installed in machine countersunk or plain holes, grip is the same as metal thickness. When countersunk head Rivnuts are to be installed in dimpled or press countersunk holes, grip is the measurement from the top surface of the metal to the underside of the dimpled hole. Maximum grip of a Rivnut is the greatest material thickness in which a specific Rivnut can be properly installed; minimum grip is the least thickness in which a specific Rivnut can be installed. The grip range is the variation of thickness between maximum and minimum. The grip range of a Rivnut can be determined from its part number; for example, a part number 6-120 Rivnut has a maximum grip of 0.120 inch. Minimum grip would equal maximum grip of the preceding Rivnut in the series (part number 6-75), or 0.075 inch. See figure 165 for method of determining Rivnut grip.

d. Installation Tools. Tools used in the installation of Rivnuts include the hand-operated and pneumatic headers and the key seating tool (fig. 166). The hand-operated and pneumatic headers have a stud onto which the Rivnut is threaded until the head of the Rivnut is against the anvil of the header. The key seating tool is used for cutting keyways in metal. If a key seating tool

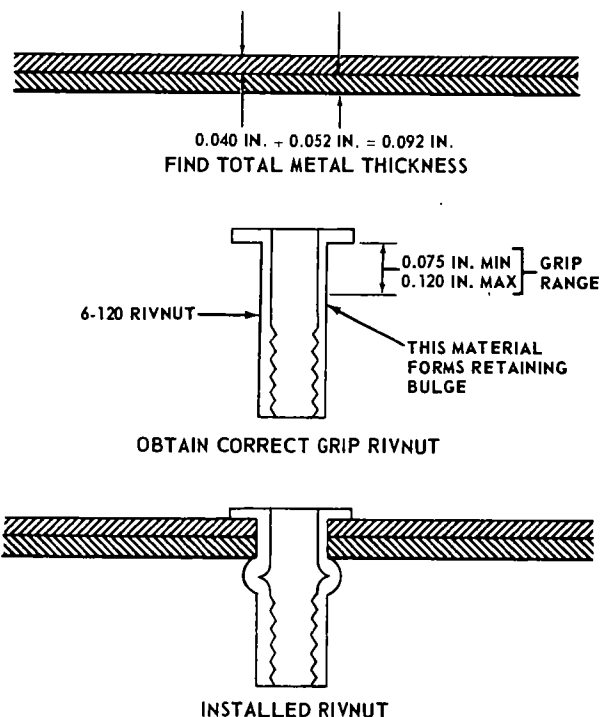


Figure 165. Determination of rivnut grip length.

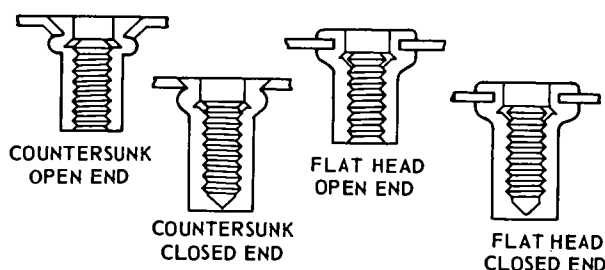


Figure 164. Types of rivnuts.

cannot be used because the metal is too thick, a small round file may be used.

e. Installation Procedures.

(1) Drill holes for Rivnuts using procedures as outlined in paragraph 102b. If keyed Rivnuts are to be used, cut the keyway after the hole has been reamed. In cutting the keyway, hold the keyway setter so it makes a 90-degree angle with the work. Also, cut the keyway on the side of the hole away from the edge of the sheet, especially when the Rivnut is used on the outside row. Operate the keyway setter by inserting it in the hole and squeezing the handles. The use of flush Rivnuts is limited. For metal which has a thickness greater than the minimum grip length of the first rivet of a series, use the machine countersink; and for metal thinner than the minimum grip length of the first rivet, use the dimpling process. Don't use the countersunk Rivnut unless the metal is thick enough for machine countersinking, or unless the underside is accessible for the dimpling operation. For a countersunk Rivnut the sheets to be joined can usually be machine countersunk. This method is preferred because

the bearing surface in a dimpled hole in one sheet of average gage will normally occupy the entire gripping surface of the Rivnut, thus limiting its grip range to that of an anchored nut only. Aside from the countersinking operation, the procedure for installing a flush Rivnut is the same as that for the flat head Rivnut.

(2) When installing Rivnuts, check the threaded stud of the heading tool to see that it is free from burs and chips from the previous installation. Then screw the Rivnut on the stud until the head touches the anvil. Insert the Rivnut in the hole (with the key positioned in the keyway, if a key is used) and hold the heading tool at right angles to the work. Press the head of the Rivnut tightly against the sheet while slowly squeezing the handles of the heading tool together until the Rivnut starts to head over. Then release the handle, and screw the stud further into the Rivnut. This prevents stripping the threads of the Rivnut before it is properly headed. Again squeeze the handles together until the Rivnut heading is complete. Remove the stud of the heading tool from the Rivnut by turning the crank counterclockwise.

(3) The action of the heading tool draws the Rivnut against the anvil, causing a bulge to form in the counterbored portion of the Rivnut on the inaccessible side of the work. This bulge is comparable to the shop head on a solid shank rivet. The amount of squeeze required to head the Rivnut properly is best determined by practice. Avoid stripping the thread in the Rivnut.

(4) The installation of a Rivnut is incomplete unless it is plugged either with one of the plugs designed for that purpose or with a screw. A Rivnut does not develop its full strength when left hollow. Any screw of proper thread size and suitable head style can be used in a Rivnut. Screws and plugs for deicing equipment is available in 6-32 thread size only.

f. Removal Procedures. Rivnuts can be drilled out by using the same size drill as used for the original hole. Since the Rivnut is hollow, the drill is guided throughout the drilling operation. The same size Rivnut can be installed in the same hole if desired.

108. Hi-Shear Rivets

a. Description. The Hi-Shear rivet consists of two parts, the pin and the collar, and is essentially a threadless bolt (fig. 167). Hi-Shear rivets are classified as special rivets but are not of the blind type. Access to both sides of the material is required to install this type of rivet. Hi-Shear rivets have the same shear strength as bolts of equal diameters, about 40 percent of the weight of a bolt, and require only about one-

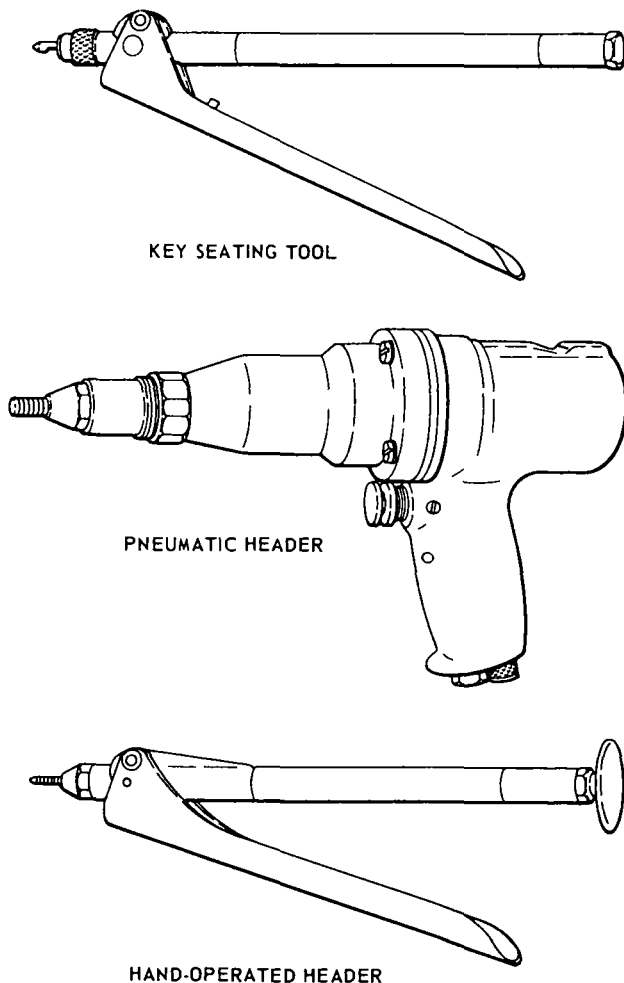


Figure 166. Rivnut installation tools.

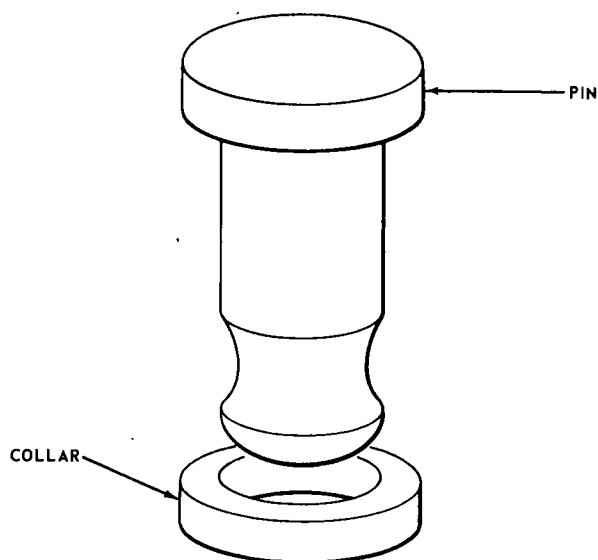


Figure 167. Hi-Shear (pin) rivet.

fifth as much time for installation as a bolt, nut, and washer combination. They are approximately three times as strong as solid shank rivets. The pin is headed at one end and is grooved about the circumference at the other. The collar is swaged onto the grooved end, effecting a firm, tight fit. Hi-Shear rivets are fabricated in a variety of materials but should be used only in shear applications. They should never be used where the grip length is less than the shank diameter.

b. Installation Tools. Hi-Shear rivets are installed with a Hi-Shear set, utilizing standard bucking bars and pneumatic guns or squeezers described in section II. The Hi-Shear set forms the collar over the grooved end of the pin, trims excess material from the collar, and discharges it through a discharge port. A separate size set is required for each shank diameter. Special Hi-Shear reverse bucking bars are used for driving Hi-Shear rivets from the head end.

c. Installation Procedures. Prepare holes for Hi-Shear rivets as outlines in section II. It may be necessary to spot-face the area under the head of the pin so that the head of the pin can fit tight against the material when the surface is not level. The spot-faced area should be 1/16 inch larger in diameter than the head diameter. Determine correct grip length by inserting the correct diameter pin in the drilled hole, and checking straight portion on shank. The straight portion on shank should not extend more than 1/16 inch through the material. High-Shear rivets may be driven from either end. To drive from collar end, refer to figure 168. If reverse riveting (driving from head end) is required, proceed as follows:

(1) Insert pin in rivet hole.

(2) Slip collar over pin.
(3) Place correct Hi-Shear rivet set in special Hi-Shear bucking bar and place rivet set against collar of rivet.

(4) Apply pressure against the rivet head with a flush rivet set and pneumatic rivet gun until the collar is formed and excess collar material is trimmed off.

d. Inspection. Inspect Hi-Shear rivets on both sides of the material. The head of the rivet should not be marred and should fit tightly against the material. Figure 169 shows acceptable and unacceptable driven rivets.

e. Removal Procedures. Any of the following methods may be used for removing Hi-Shear rivets:

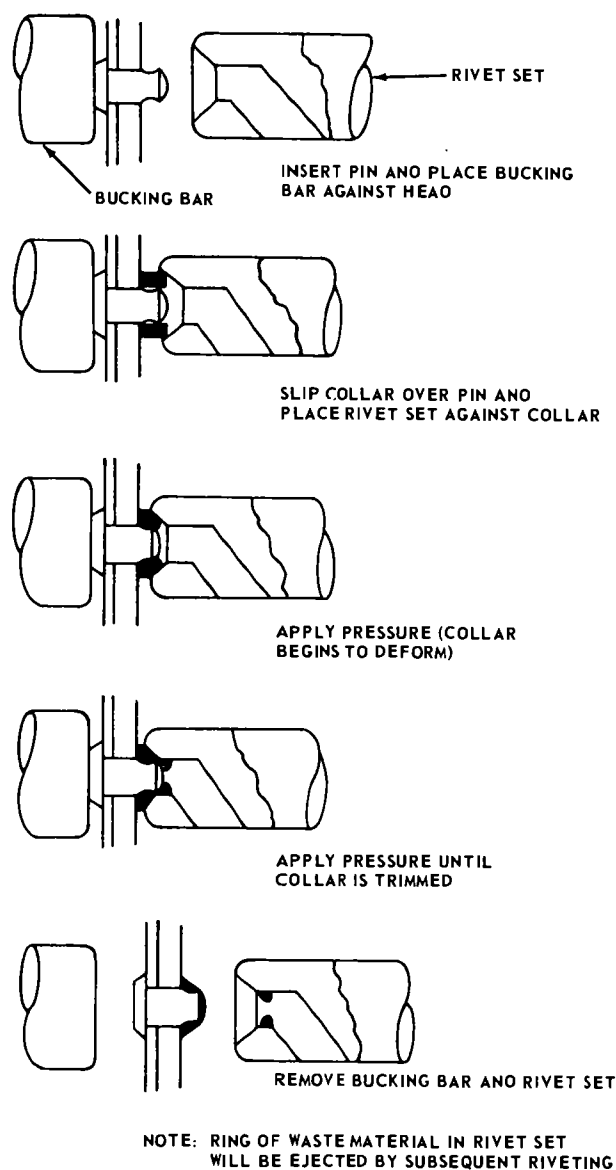


Figure 168. Driving Hi-Shear rivets from collar end.

(1) Apply a narrow cape chisel to the slope of the collar and a bucking bar to the opposite side of the collar. Hit the chisel with a medium-weight hammer, and cut collar. Pry collar off and punch out pin.

(2) Apply drill-out bushing to the collar end of the rivet. Drill off end of rivet and punch out pin.

(3) Apply drill-out bushing to head of rivet. Drill head off and punch out pin.

(4) Apply a punch (installed on a rivet squeezer) to collar end of pin. Punch out pin.

(5) Apply a hollow mill cutter (installed in drill motor) to collar. Grind collar to loosen and punch out pin.

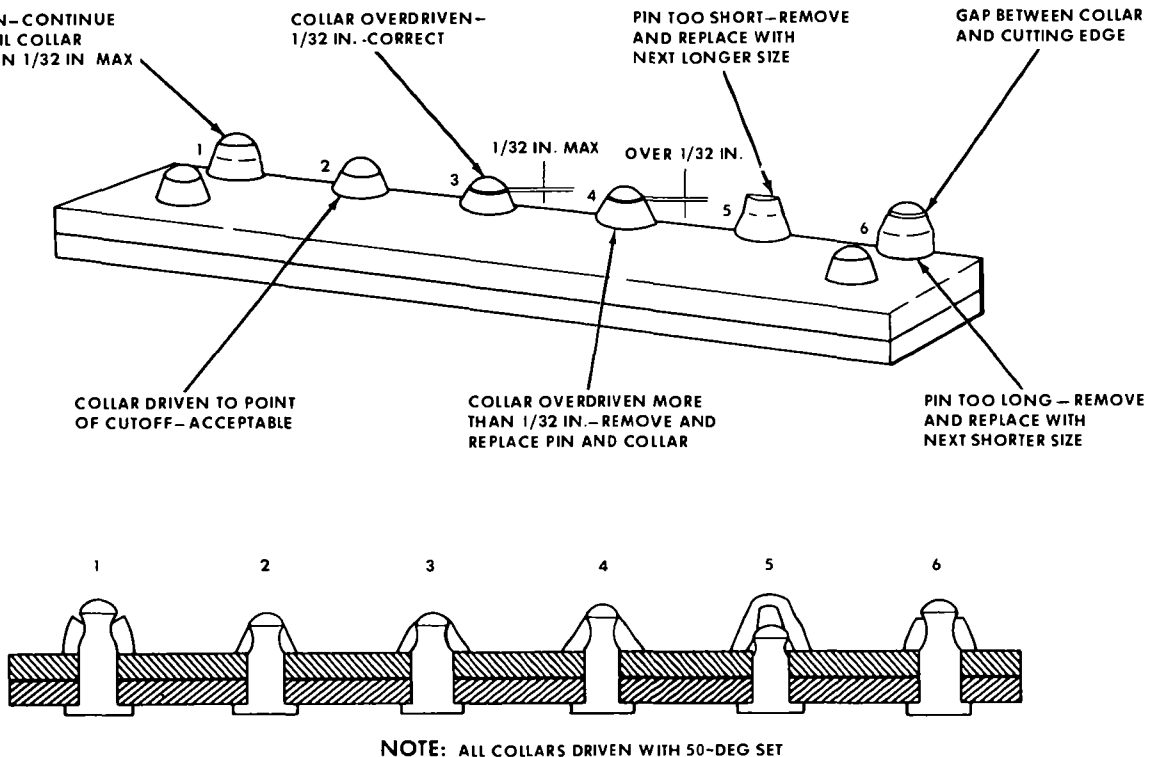


Figure 169. Hi-Shear rivet inspection.

Section IV. SPECIAL PURPOSE BOLTS

109. Huck Lockbolts

The Huck lockbolt is a form of bolt, combining the features of both a high strength bolt and a rivet, with advantages over each. The Huck lockbolt is generally used in wing splice fittings, landing gear fittings, fuel cell fittings, longerons, beams, skin splice plates, and other major structural attachments. It is easier and more quickly installed than the conventional rivet or bolt, and eliminates the use of lockwashers, cotter pins, and special nuts. Like the rivet, the lockbolt requires a pneumatic gun or pull gun for installation. When installed, the lockbolt is rigidly and permanently locked in place.

a. Types of Lockbolts. Three types of Huck lockbolts are commonly used, the pull-type, the stump-type, and the blind-type (fig. 170). Pull- and stump-type lockbolts are available in 3/16-, 1/4-, 5/16-, and 3/8-inch diameters with modified brazier, pan, and countersunk heads. Blind lock-

bolts are available in oversize 1/4- and 5/16-inch diameters. Common features of the three types of lockbolts are the annular locking grooves on the pin and the locking collar which is swaged into the pin's lock grooves to lock the pin in tension. The pins of pull- and blind-type lockbolts are extended for pull installation, and the extension is provided with pulling grooves and a tension breakoff groove.

(1) *Pull-type.* The pull-type lockbolt is mainly used in aircraft primary and secondary structure. It is installed very rapidly and has approximately one-half the weight of equivalent AN or MS steel bolts and nuts. A special pneumatic pull gun is required for installation of this type lockbolt, which can be performed by one operator since bucking is not required.

(2) *Stump-type.* The stump-type lockbolt, although not having the extended stem with pull grooves, is a companion fastener to the

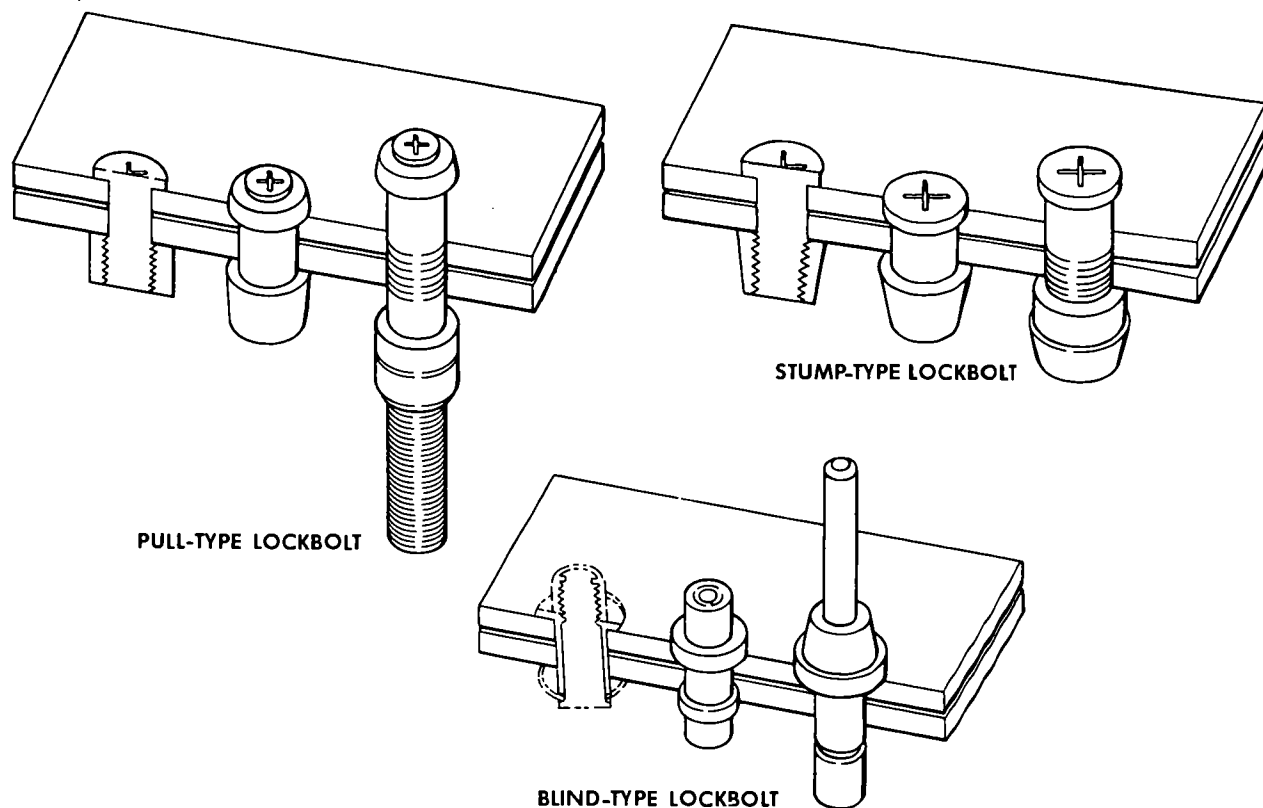


Figure 170. Types of lockbolts.

pull-type lockbolt. It is used primarily where clearance will not permit effective installation of the pull-type lockbolt. It is driven with a standard pneumatic riveting gun, with a hammer set attached for swaging the collar into the pin locking grooves, and a bucking bar.

(3) *Blind-type.* The blind-type lockbolt comes as a complete unit or assembly and has exceptional strength and sheet pull-together characteristics. Blind-type lockbolts are used where only one side of the work is accessible, and generally where it is difficult to drive a conventional rivet. This type lockbolt is installed in a manner similar to the pull-type lockbolt.

Note. Blind-type lockbolts are not to be used in places where the backup sheet is 0.020 inch gage or less.

b. Composition. The pins of pull- and stump-type lockbolts are made of heat-treated alloy steel or high-strength aluminum alloy. Companion collars are made of aluminum alloy or mild steel. The blind-type lockbolt consists of a heat-treated alloy steel pin, blind sleeve, filler sleeve, mild steel collar, and carbon steel washer.

c. Uses. Alloy steel lockbolts may be used to replace steel Hi-Shear rivets, solid steel rivets, and AN or MS bolts of the same diameter and head type. Aluminum alloy lockbolts may be used to replace 7075-T aluminum alloy Hi-Shear rivets and solid aluminum alloy rivets of the same dia-

meter and head type. Steel and aluminum alloy

Table 36. Grip Range for Pull- and Stump-Type Lockbolts

Grip No	Grip range	
	Min (in.)	Max (in.)
1	0.031	0.094
2	0.094	0.156
3	0.156	0.219
4	0.219	0.281
5	0.281	0.344
6	0.344	0.406
7	0.406	0.469
8	0.469	0.531
9	0.531	0.594
10	0.594	0.656
11	0.656	0.718
12	0.718	0.781
13	0.781	0.843
14	0.843	0.906
15	0.906	0.968
16	0.968	1.031
17	1.031	1.094
18	1.094	1.156
19	1.156	1.219
20	1.219	1.281
21	1.281	1.344
22	1.344	1.406
23	1.406	1.469
24	1.469	1.531
25	1.531	1.594
26	1.594	1.656
27	1.656	1.718
28	1.718	1.781
29	1.781	1.843
30	1.843	1.906
31	1.906	1.968
32	1.968	2.031
33	2.031	2.094

lockbolts may also be used to replace steel and 2024-T aluminum alloy bolts of the same diameter, respectively. Blind lockbolts may be used to replace solid aluminum alloy rivets, stainless steel rivets, and all blind rivets of the same diameter. For shear applications, the blind-type lockbolt may be used to replace aluminum alloy or steel AN or MS bolts, AN or MS screws, and Hi-Shear rivets of the same diameter.

d. Selection.

(1) *Determining grip range.* Determine the lockbolt grip range required by measuring the thickness of the material with a hook scale. The measurement should be made with the material clamped and including variations due to tolerances in sheet thickness, primer, and any spaces existing between the sheets due to irregularities in contour. Refer to tables 36 and 37 for grip ranges of pull-, stump-, and blind-type lockbolts, respectively.

(2) *Part numbering system.* The part numbering system for pull-, stump-, and blind-type lockbolts is shown in figures 171, 172, and 173, respectively. Figure 174 illustrates the part numbering system for lockbolt collars.

Table 37. Grip Range for Blind-Type Lockbolts

Grip No.	1/4-in. diameter		Grip No.	5/16-in. diameter	
	Min (in.)	Max (in.)		Min (in.)	Max (in.)
1	0.031	0.094	2	0.094	0.156
2	0.094	0.156	3	0.156	0.219
3	0.156	0.219	4	0.219	0.281
4	0.219	0.281	5	0.281	0.344
5	0.281	0.344	6	0.344	0.406
6	0.344	0.406	7	0.406	0.469
7	0.406	0.469	8	0.469	0.531
8	0.469	0.531	9	0.531	0.594
9	0.531	0.594	10	0.594	0.656
10	0.594	0.656	11	0.656	0.718
11	0.656	0.718	12	0.718	0.781
12	0.718	0.781	13	0.781	0.843
13	0.781	0.843	14	0.843	0.906
14	0.843	0.906	15	0.906	0.968
15	0.906	0.968	16	0.968	1.031
16	0.968	1.031	17	1.031	1.094
17	1.031	1.094	18	1.094	1.156
18	1.094	1.156	19	1.156	1.219
19	1.156	1.219	20	1.219	1.281
20	1.219	1.281	21	1.281	1.343
21	1.281	1.343	22	1.343	1.406
22	1.343	1.406	23	1.406	1.469
23	1.406	1.469	24	1.469	1.531
24	1.469	1.531			
25	1.531	1.594			

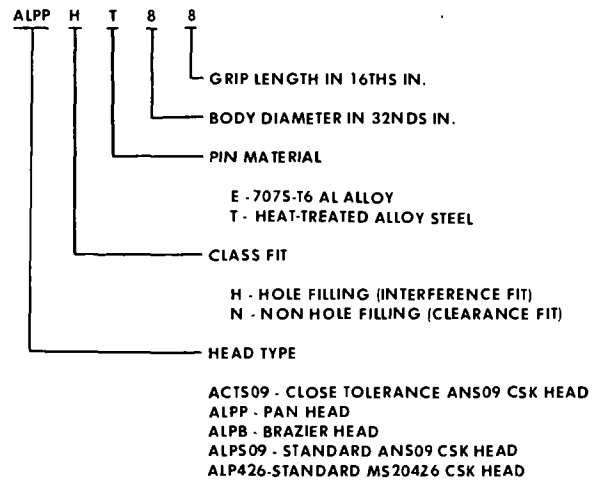


Figure 171. Pull-type lockbolt numbering system.

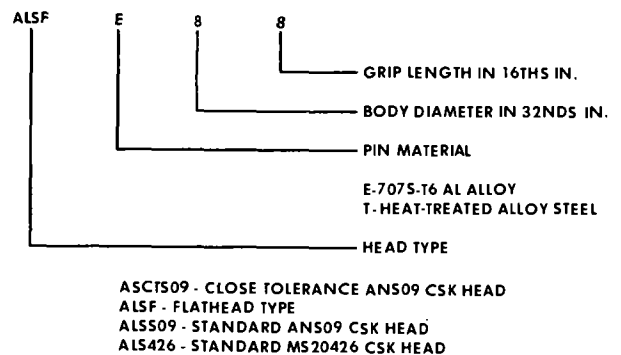


Figure 172. Stump-type lockbolt numbering system.

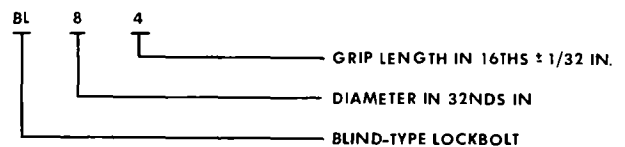


Figure 173. Blind-type lockbolt numbering system.

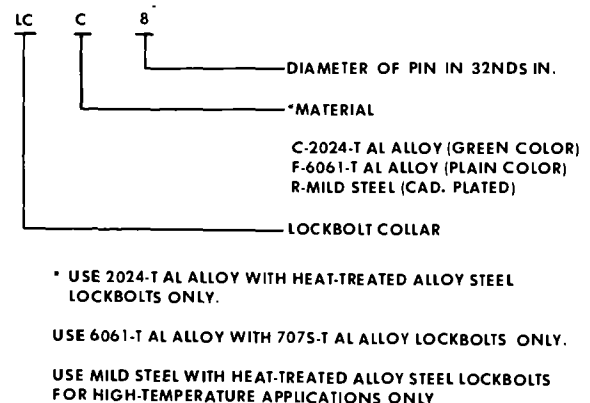
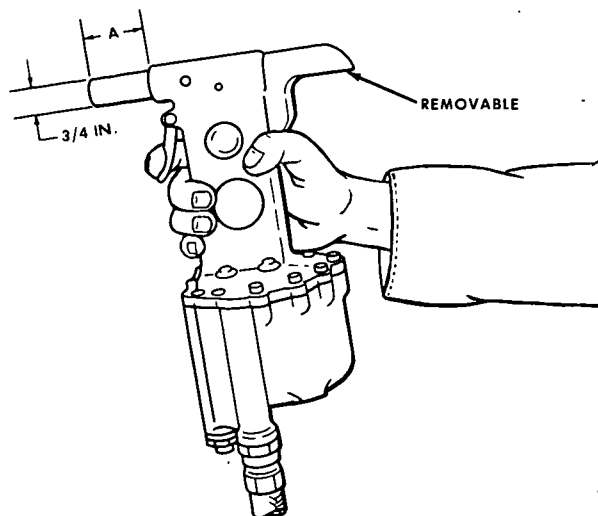


Figure 174. Lockbolt collar numbering system.

e. *Installation Tools.* Rivet pull guns as shown in figures 175 and 176 are used to install pull- and blind-type lockbolts. Tools for installing stump-type lockbolts are given in table 38.

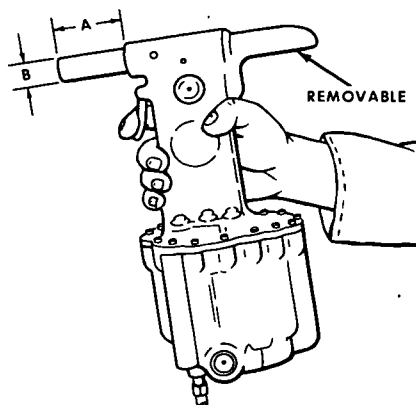
f. *Installation Procedures.*

(1) *Drilling procedures.* Lockbolts require that the holes shall be round and within size limits as specified in tables 39 and 40.



BLIND	PULL	WEIGHT: 8 POUNDS					
LOCKBOLT DIA (IN.)	LOCKBOLT DIA (IN.)	STD. NOSE (IN.)	A (IN.)	SHORT NOSE (IN.)	A (IN.)	LONG NOSE (IN.)	A (IN.)
1/4	3/16	79606	2	79616	1-3/32	79613	3-1/2
	1/4	79608	2	79618	1-3/32	79615	3-1/2

Figure 175. CP352 rivet gun for pull- and blind-type aluminum lockbolts.



BLIND	PULL	WEIGHT: 11 POUNDS							
LOCKBOLT DIA (IN.)	LOCKBOLT DIA (IN.)	STD. NOSE (IN.)	A (IN.)	B (IN.)	LONG NOSE (IN.)	A (IN.)	B (IN.)	ADAPTER NOSE (IN.)	A (IN.) B (IN.)
1/4	3/16							79651	2-3/4 3/4
5/16	1/4	79582	2-11/16	1-1/16	79587	4-3/16	1-1/16	79669 87548	3-1/16 3/4 1-15 16 3/4
-	5/16	79584	2-11/16	1-1/16	79589	4-3/16	1-1/16		
-	3/8	79586	2-11/16	1-1/16	79591	4-3/16	1-1/16		

Figure 176. CP353 rivet gun for pull- and blind-type steel lockbolts.

(2) *Installation of pull-type lockbolts.* Installation of the pull-type lockbolt is automatic and continuous in the following sequence (fig. 177):

(a) Insert pin from one side of work; then place locking collar over extending lockbolt pin tail.

(b) Apply gun; chuck jaws automatically engage pull grooves of extending pin tail.

(c) Depress gun trigger, thus causing a pull to be exerted on the pin, pulling the collar against the swaging anvil and drawing the work tightly together. After the faying surfaces are in close contact, the pin is pulled into an interference or clearance fit hole. As the pull on the pin increases, the anvil of the tool is drawn over the collar, swaging the collar into locking grooves of the pin to form a rigid, permanent

Table 38. Standard Tools for Stump-Type Lockbolts

Stump-type lockbolt size (in.)	Swaging set			Applicable air hammers			
	Huck part no.	Shank size (in.)	Length (in.)	CP3X or equal	CP4X or equal	CP5X or equal	CP7X or equal
$\frac{3}{16}$	915-1-6A	0.401	2 $\frac{3}{8}$	X	X		
$\frac{1}{4}$	915-1-8A	0.401	2 $\frac{3}{8}$	----	----	X	X
$\frac{5}{16}$	915-1-10A	0.498	3 $\frac{1}{2}$	----	----	----	X
$\frac{3}{8}$	915-1-12A	0.498	3 $\frac{1}{2}$	----	----	----	X

Table 39. Drilling Procedures for Pull- and Stump-Type Lockbolts

	CLEARANCE FIT APPLICATION					INTERFERENCE FIT APPLICATION					
Bolt dia (in.)	Predrill		Drill size		Hole tolerance (in.)	Bolt dia (in.)	Predrill		Drill size		Hole tolerance (in.)
	Drill	dia (in.)	Drill	dia (in.)			Drill	dia (in.)	Drill	dia (in.)	
3/16	18	0.1695	11	0.191	0.191–0.203	3/16	18	0.169	13	0.185	0.185–0.187
1/4	1	0.228	1/4	0.250	0.250–0.265	1/4	1	0.228	C	0.242	0.242–0.246
5/16	L	0.290	5/16	0.312	0.312–0.330	5/16	L	0.290	N	0.302	0.302–0.306
3/8	11/32	0.343	3/8	0.375	0.375–0.395	3/8	11/32	0.343	U	0.368	0.368–0.371

Table 40. Drilling Procedures for Blind-Type Lockbolts

Bolt dia (in.)	Predrill		Drill size		Hole tolerance (in.)
	Drill	Dia (in.)	Drill	Dia (in.)	
$\frac{1}{4}$	D	0.246	G	0.261	0.261-0.265
$\frac{5}{16}$	$2\frac{1}{64}$	0.328	S	0.348	0.348-0.352

lock. Continued buildup of force automatically breaks the lockbolt pin in tension at the break-neck groove, and the pin tail is automatically ejected. When the gun piston returns to its initial forward position, the ejector advances to disengage anvil from swaged collar.

(3) *Installation of stump-type lockbolts.* To install the stump-type lockbolt, refer to figure 178 and proceed as follows:

(a) Insert pin from one side of work. Be sure pin fills hole, as stump pins of alloy steel do not expand to fill oversize holes. Slip lockbolt collar over extending locking grooves of pin; then place a bucking bar against head of pin.

Note. Be sure sheets are clamped firmly together to avoid sheet separation.

(b) Place swaging set over collar, align it with pin, and apply driving pressure until soft collar is forced into locking grooves of ex-

tended stump shank. If possible, hold drive set and gun 90° to face of work. Continue to apply pressure until head is fully formed. The straight positions of the shank will be flush or protrude not more than 1/32 inch from the work.

(c) Lockbolt stump collars can be driven on a surface not exceeding 7° from a perpendicular with axis of hole. The manufactured head of the lockbolt stump must be driven on a surface perpendicular with axis of hole. Spot-face for other conditions.

(4) *Installation of blind-type lockbolts.* Installation of the blind-type lockbolt is basically the same as for the pulltype. See figure 179 for installation instructions.

Note. All lockouts are lubricated and must not be degreased if proper driving characteristics are to be maintained.

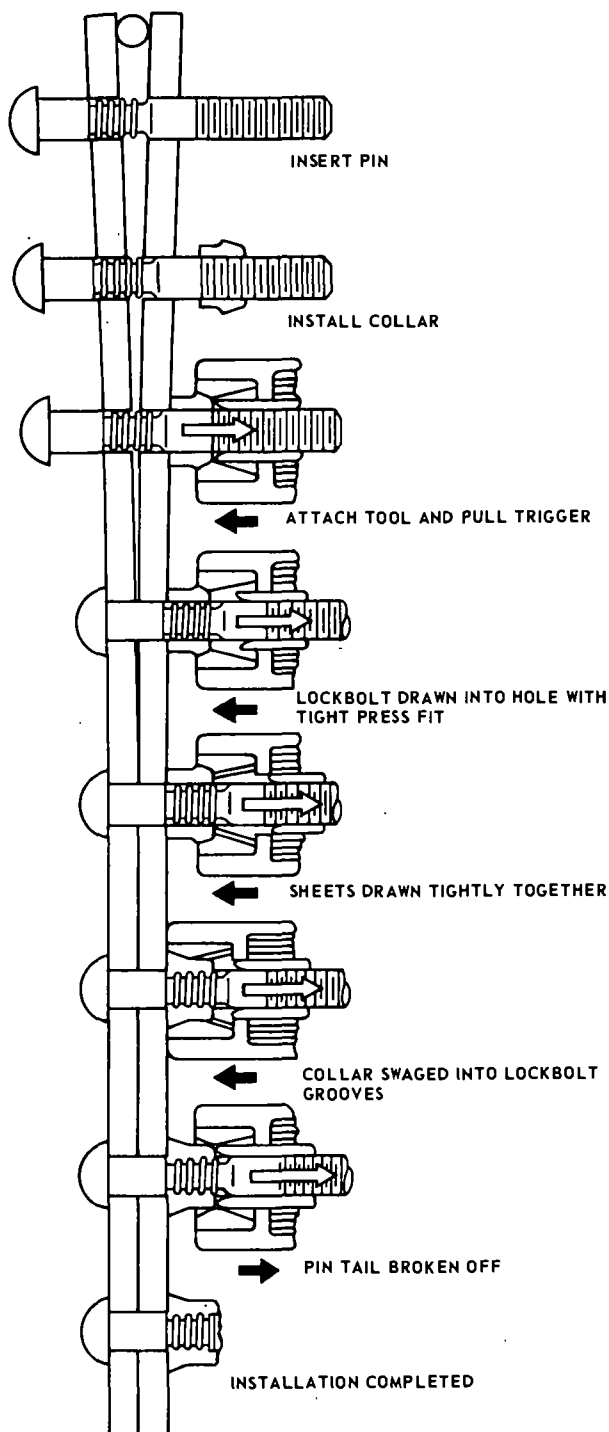


Figure 177. Installation of pull-type lockbolt.

(5) *Inspection.* The lockbolt collar shall be swaged substantially throughout the complete length of the collar. The tolerance of the broken end of pin relative to top of collar will be within the dimensions shown as follows:

- $\frac{3}{16}$ -inch diameter pin-
0.079 inch below to 0.032 inch above.
- $\frac{1}{4}$ -inch diameter pin-
0.079 inch below to 0.050 inch above.

$\frac{5}{16}$ -inch diameter pin-
0.079 inch below to 0.050 inch above.

$\frac{3}{8}$ -inch diameter pin-
0.079 inch below to 0.060 inch above.

(6) *Removal procedure.* When removal of a lockbolt becomes necessary, remove collar by splitting axially with a sharp cold chisel. Exercise care not to break out or deform hole. Use of a backup bar on opposite side of collar being split is recommended. The pin may then be driven out with a drift.

Note. If the lockout is carefully removed, another lockbolt of the same diameter may be used as a replacement, since the hole is enlarged only slightly. It is possible to make several replacements in the same hole and still maintain an interference fit.

110. Jo-Bolts

Jo-Bolts are high-strength structural blind fasteners used in close tolerance holes where assembly does not allow installation of AN, NAS, or MS bolts or, in some cases, where the installation of Jo-Bolts may be required for weight saving advantages. However, in all cases, Jo-Bolts are always considered to be a part of the permanent structure and primarily subject to shear loads. The Jo-Bolt, installed as a unit, consists of a bolt, nut, and sleeve. Jo-Bolts are identified by head type as follows:

a. Head Types.

(1) *Flush-type (F).* The flush-type Jo-Bolt normally takes the same size countersink or dimple required for the same corresponding size AN509 screw head. The nut and bolt are made of alloy steel. The sleeve is of annealed corrosion-resistant steel. All components are cadmium plated. See figure 180 for nominal sizes.

(2) *Hex-type (P and PA).* Both hex-type Jo-Bolts have an alloy steel bolt and an annealed corrosion-resistant sleeve. Both the bolt and sleeve are cadmium plated. See figure 181 for nominal sizes.

(3) *Millable hex-type (FA).* The millable hex-type Jo-Bolt normally takes the same size countersink or dimple required for the corresponding size MS20426 rivet. The bolt is alloy steel and the sleeve is corrosion-resistant steel, both cadmium plated. The nut is aluminum alloy. After installation, the nut head is milled flush. See figure 182 for nominal sizes.

(4) *Oversize-type (FO and PO).* The oversize-type Jo-Bolt is used in special applications where the hole size has been exceeded and standard Jo-Bolts cannot be used. The head size and material specifications of the FO- and PO-type Jo-Bands are the same as the F- and P-types, respectively, the only difference being size of nut shank diameter. See figures 180 and 181 for nominal sizes.

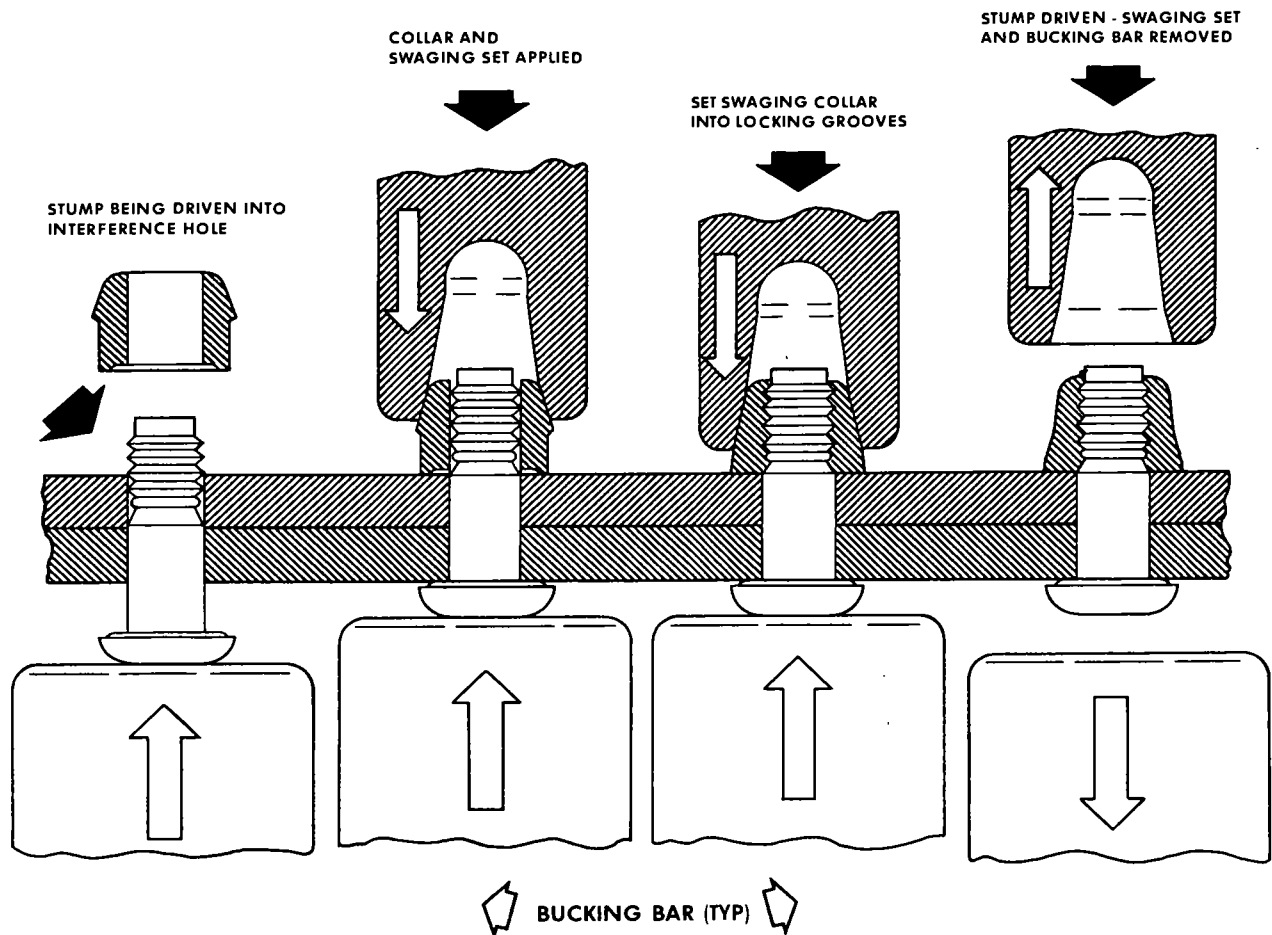


Figure 178. Installation of stump-type lockbolt.

(5) *Flush-type (426F)*. The flush-type head is designed to fit in a counter-sunk or dimpled hole prepared for an MS20426 rivet. Nut shank size and material specifications are the same as the F-type Jo-Bolt. See figure 180 for nominal sizes.

b. Uses. The high shear and tension strength of Jo-Bolts makes them suitable for use in areas of high stresses where other blind fasteners would not be practical. They are used in areas which are not often subjected to replacement or servicing. Because Jo-Bolts are three-part fasteners, they should not be used where any part, in becoming loose, could be drawn into the engine air intake.

c. Selection. Determine the Jo-Bolt grip range required by measuring the thickness of the material with a hook scale. The measurement should be made with the material clamped and including variations due to tolerances in sheet thickness, primer, and any spaces existing between the sheets due to irregularities in contour. See figures 180, 181, and 182 for grip ranges of Jo-Bolts.

d. Installation Tools. Jo-Bolts are installed

with special tools and equipment shown in figure 183.

e. Installation Procedures. Pilot and ream drill sizes for Jo-Bolts are listed in figures 180, 181, and 182. Hole size should be such that the selected Jo-Bolt can be easily pushed through the hole. In no case should the Jo-Bolt be forcibly driven through the hole. A very light tap is permissible in aluminum alloys but not in steel. Insert Jo-Bolt in drilled hole and drive Jo-Bolt as follows:

- (1) Select the proper combination of tools (fig. 183).

- (2) Engage the slatted portion of the bolt shank with the nose adapter of the tool. Make sure the cogs on the nose engage the nut.

- (3) Hold the driving tool down tightly against the head of the Jo-Bolt and perpendicular to the work. Failure to do so may result in the stem breaking off before the Jo-Bolt is tight.

- (4) Apply power. As power is applied, the bolt is turned while the nut is held. The sleeve, compressed between the bolt head and the control end of the nut, is drawn over the taper. The sleeve is expanded, forming the blind head

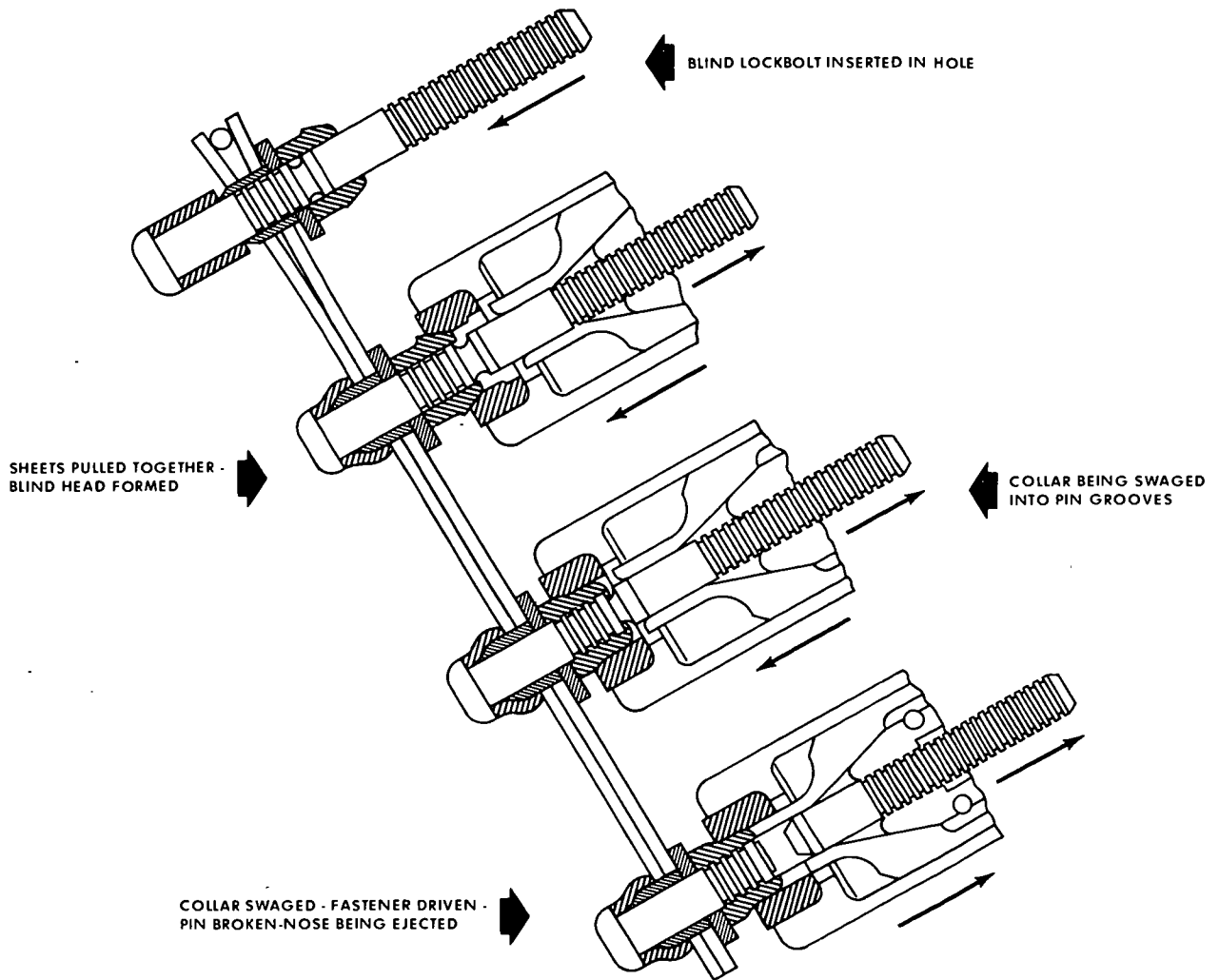


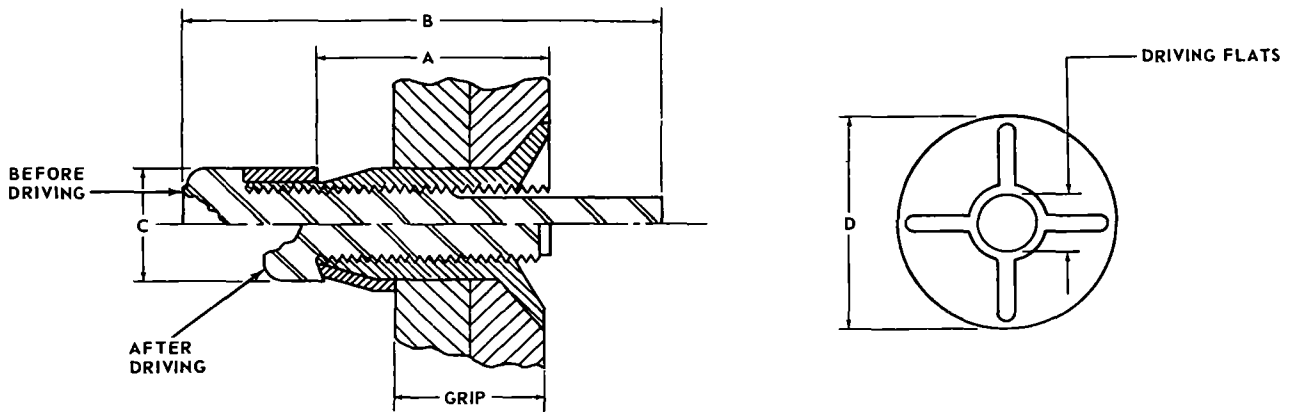
Figure 179. Installation of blind-type lockbolt.

against the surface of the inner member. As driving is completed, the slabbed portion of the bolt is snapped off and ejected from the tool.

(5) Touch up the end of the bolt at the breakoff point, after driving is completed, with

zinc chromate primer, Military Specification MIL-P-8585.

f. Removal Procedures. If necessary to remove a Jo-Bolt, use a drill with a speed of 500 rpm or under and remove as shown in figure 184 or 185. Use drill size as listed in table 41.

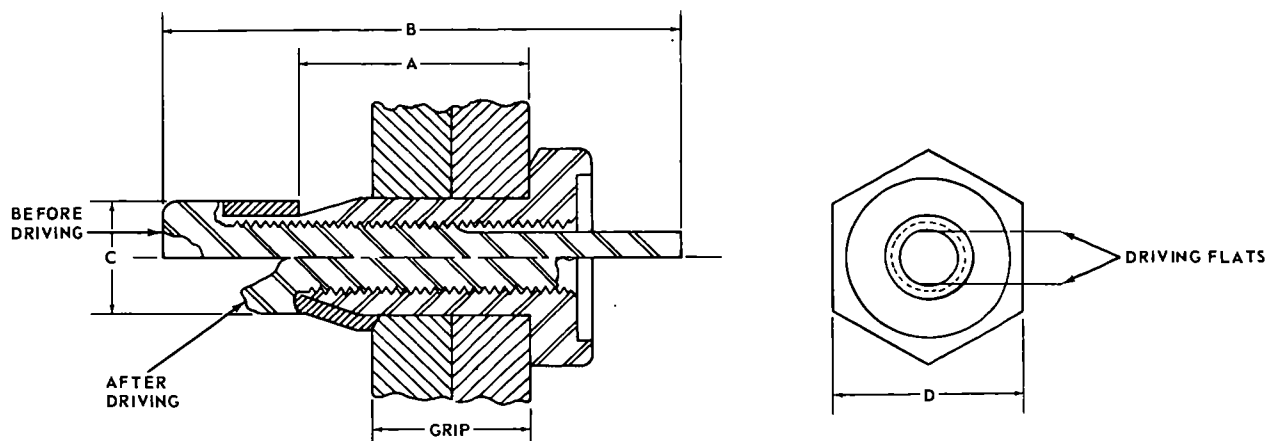


BOLT SIZE			NO. 8 NOMINAL		NO. 10 NOMINAL		1/4 NOMINAL		5/16 NOMINAL		3/8 NOMINAL	
DASH NO.	GRIP RANGE		A ±0.015	B ±0.015	A ±0.015	B ±0.015	A ±0.015	B ±0.015	A ±0.015	B ±0.015	A ±0.015	B ±0.015
	MIN	MAX										
2	0.094	0.156	0.230	0.733	0.228	0.853	0.256	0.881				
3	0.156	0.219	0.293	0.795	0.291	0.916	0.319	0.944	0.344	1.096	0.417	1.179
4	0.219	0.281	0.355	0.858	0.353	0.978	0.381	1.006	0.406	1.158	0.479	1.242
5	0.281	0.344	0.418	0.920	0.416	1.041	0.444	1.069	0.469	1.221	0.542	1.304
6	0.344	0.406	0.480	0.983	0.478	1.103	0.506	1.131	0.531	1.283	0.604	1.367
7	0.406	0.469	0.543	1.045	0.541	1.166	0.569	1.194	0.594	1.346	0.667	1.429
8	0.469	0.531	0.605	1.108	0.603	1.228	0.631	1.256	0.656	1.408	0.729	1.492
9	0.531	0.594	0.668	1.170	0.666	1.291	0.694	1.319	0.719	1.471	0.792	1.554
10	0.594	0.656	0.730	1.233	0.728	1.353	0.756	1.381	0.781	1.533	0.854	1.617
11	0.656	0.719	0.793	1.295	0.791	1.416	0.819	1.444	0.844	1.596	0.917	1.679
12	0.719	0.781	0.855	1.358	0.853	1.478	0.881	1.506	0.906	1.658	0.979	1.742
13	0.781	0.844	0.918	1.420	0.916	1.541	0.944	1.569	0.969	1.721	1.042	1.804
14	0.844	0.906	0.980	1.483	0.978	1.603	1.006	1.631	1.031	1.783	1.104	1.867
15	0.906	0.969	1.043	1.545	1.041	1.666	1.069	1.694	1.094	1.846	1.167	1.929
16	0.969	1.031	1.105	1.608	1.103	1.728	1.131	1.756	1.156	1.908	1.229	1.992

PART NO.	NOM SIZE	NUT DIA C	HEAD DIA D		PILOT DRILL		FINAL REAM	
		TYPE F, FO, AND 426F	TYPE F AND FO	TYPE 426F	TYPE F AND 426F	TYPE FO	TYPE F AND 426F	TYPE FO
164	NO. 8	0.161 0.156	0.332 0.325	0.290 0.282	NO. 25 (0.150)	NO. 20 (0.161)	0.167 0.164	0.182 0.180
200	NO. 10	0.199 0.195	0.385 0.378	0.357 0.349	NO. 15 (0.180)	NO. 7 (0.201)	0.202 0.199	0.217 0.215
260	1/4	0.260 0.254	0.507 0.499	0.480 0.472	D (0.246)	G (0.261)	0.263 0.260	0.278 0.276
312	5/16	0.312 0.306	0.635 0.626	0.568 0.559	L (0.290)	N (0.302)	0.315 0.312	0.329 0.327
375	3/8	0.375 0.366	0.762 0.752	0.698 0.688	5 (0.348)	U (0.368)	0.378 0.374	0.392 0.390

NOTE:
DIMENSIONS SHOWN ARE IN INCHES.

Figure 180. Flush-head Jo-Bolts.



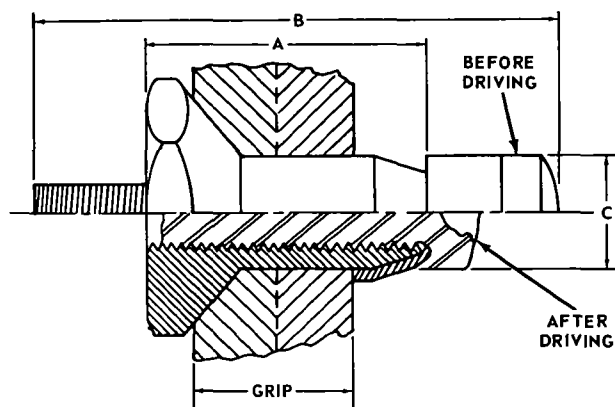
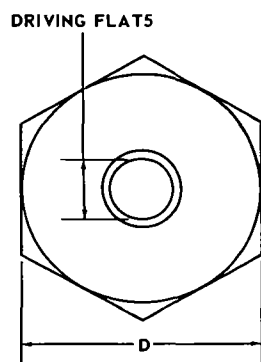
BOLT SIZE			NO. 8 NOMINAL		NO. 10 NOMINAL		1/4 NOMINAL		5/16 NOMINAL		3/8 NOMINAL	
DASH NO.	GRIP RANGE		A	B	A	B	A	B	A	B	A	B
	MIN	MAX	±0.015	±0.015	±0.015	±0.015	±0.015	±0.015	±0.015	±0.015	±0.015	±0.015
1	0.031	0.094	0.168	0.733								
2	0.094	0.156	0.230	0.795	0.228	0.936	0.256	1.006				
3	0.156	0.219	0.293	0.858	0.291	0.999	0.319	1.069	0.344	1.221	0.417	1.304
4	0.219	0.281	0.355	0.920	0.353	1.061	0.381	1.131	0.406	1.283	0.479	1.367
5	0.281	0.344	0.418	0.983	0.416	1.124	0.444	1.194	0.469	1.346	0.542	1.429
6	0.344	0.406	0.480	1.045	0.478	1.186	0.506	1.256	0.531	1.408	0.604	1.492
7	0.406	0.469	0.543	1.108	0.541	1.249	0.569	1.319	0.594	1.471	0.667	1.554
8	0.469	0.531	0.605	1.170	0.603	1.311	0.631	1.381	0.656	1.533	0.729	1.617
9	0.531	0.594	0.668	1.233	0.666	1.374	0.694	1.444	0.719	1.596	0.792	1.679
10	0.594	0.656	0.730	1.295	0.728	1.436	0.756	1.506	0.781	1.658	0.854	1.742
11	0.656	0.719	0.793	1.358	0.791	1.499	0.819	1.569	0.844	1.721	0.917	1.804
12	0.719	0.781	0.855	1.420	0.853	1.561	0.881	1.631	0.906	1.783	0.979	1.867
13	0.781	0.844	0.918	1.483	0.916	1.624	0.944	1.694	0.969	1.846	1.042	1.929
14	0.844	0.906	0.980	1.545	0.978	1.686	1.006	1.756	1.031	1.908	1.104	1.992
15	0.906	0.969	1.043	1.608	1.041	1.749	1.069	1.819	1.094	1.971	1.167	2.054
16	0.969	1.031	1.105	1.670	0.103	1.811	1.131	1.881	1.156	2.033	1.229	2.117

PART NO.	NOM SIZE	NUT DIA C	HEAD DIA D		PILOT DRILL		FINAL REAM	
		TYPE P, PO, AND PA	TYPE P AND PO	TYPE PA	TYPE PO	TYPE P AND PA	TYPE P AND PA	TYPE PO
164	NO. 8	0.161 0.156	0.250 0.244	0.283 0.277	NO. 20 (0.161)	NO. 25 (0.150)	0.167 0.164	0.182 0.180
200	NO. 10	0.199 0.195	0.312 0.305	0.346 0.332	NO. 7 (0.201)	NO. 15 (0.180)	0.202 0.199	0.217 0.215
260	1/4	0.260 0.254	0.375 0.367	0.472 0.458	G (0.261)	D (0.246)	0.263 0.260	0.278 0.276
312	5/16	0.312 0.306	0.437 0.429		N (0.302)	L (0.290)	0.315 0.312	0.329 0.327
375	3/8	0.375 0.366	0.500 0.491		U (0.368)	5 (0.348)	0.378 0.374	0.392 0.390

NOTES:

1. PA TYPE NOT AVAILABLE IN THESE SIZES.
2. DIMENSIONS SHOWN ARE IN INCHES.

Figure 181. Hex-head Jo-Bolts.



BOLT SIZE			NO. 8 NOMINAL		NO. 10 NOMINAL		1/4 NOMINAL	
DASH NO.	GRIP RANGE		A ± 0.015	8 ± 0.015	A ± 0.015	B ± 0.015	A ± 0.015	B ± 0.015
	MIN	MAX						
1								
2	0.094	0.156	0.305	0.795	0.308	0.936	0.366	
3	0.156	0.219	0.368	0.858	0.371	0.999	0.399	
4	0.219	0.281	0.430	0.920	0.433	1.061	0.461	
5	0.281	0.344	0.493	0.983	0.496	1.124	0.524	
6	0.344	0.406	0.555	1.045	0.558	1.186	0.586	
7	0.406	0.469	0.618	1.108	0.621	1.249	0.649	
8	0.469	0.531	0.680	1.170	0.683	1.311	0.711	
9	0.531	0.594	0.743	1.233	0.746	1.374	0.774	
10	0.594	0.656	0.805	1.295	0.808	1.437	0.836	
11	0.656	0.719	0.868	1.358	0.871	1.499	0.899	
12	0.719	0.781	0.930	1.420	0.933	1.561	0.961	
13	0.781	0.844	0.993	1.483	0.996	1.624	1.024	
14	0.844	0.906	1.055	1.545	1.058	1.686	1.086	
15	0.906	0.969	1.118	1.608	1.121	1.749	1.149	
16	0.969	1.031	1.180	1.670	1.183	1.811	1.211	
PART NO.	NOM SIZE	NUT DIA C		HEAD DIA D		PILOT DRILL		FINAL REAM
164	NO. 8	0.161	0.156	0.283	0.277	NO. 25 (0.150)		0.167 0.164
200	NO. 10	0.199	0.195	0.346	0.332	NO. 15 (0.180)		0.202 0.199
260	1/4	0.260	0.254	0.472	0.458	D (0.246)		0.263 0.260

NOTE:
DIMENSIONS SHOWN ARE IN INCHES.

Figure 182. Millable hex-head Jo-Bolts.

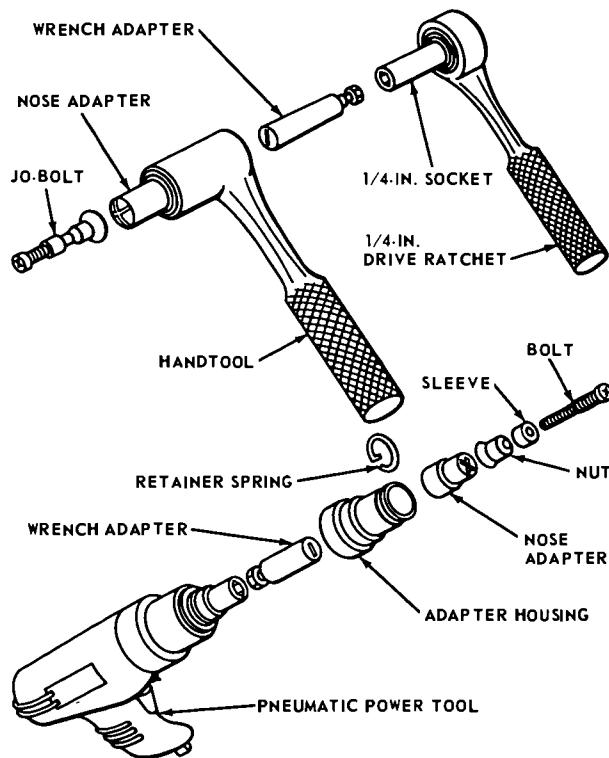


Figure 183. Jo-Bolt installation tools.

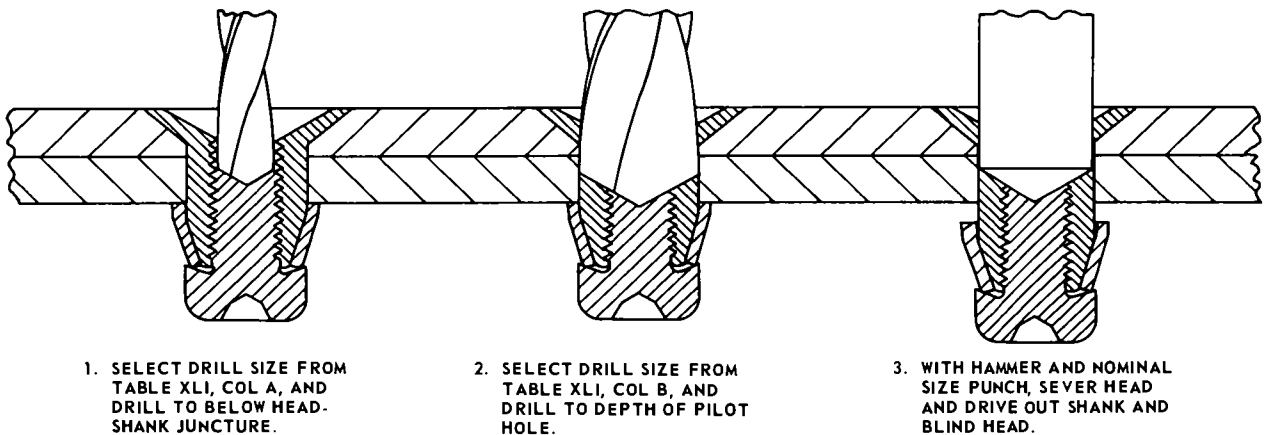


Figure 184. Removal of Jo-Bolts installed too short.

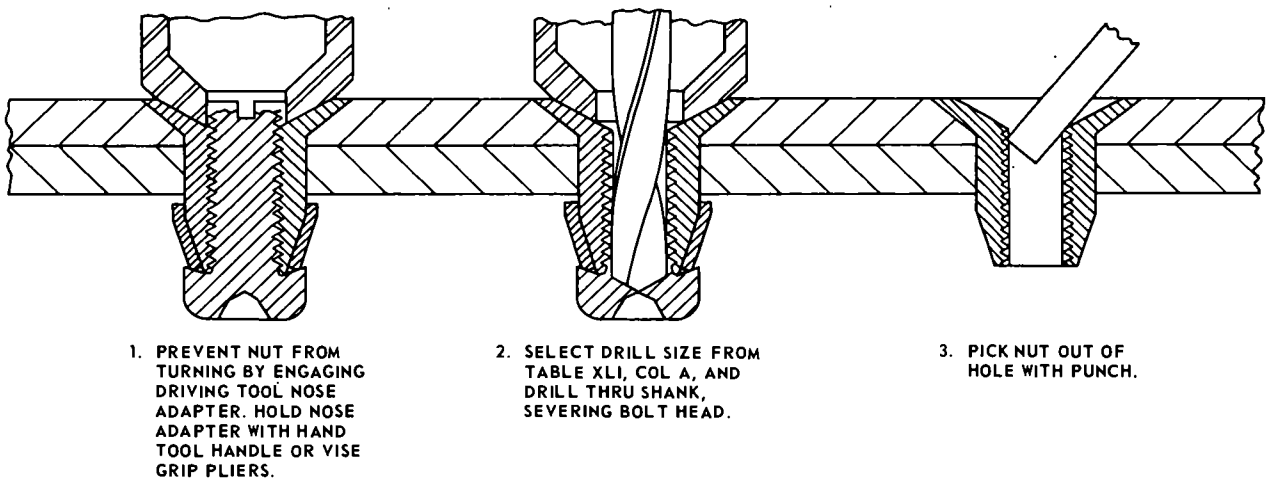


Figure 185. Removal of Jo-Bolts installed too long.

Table 41. Drill sizes for removing Jo-Bolts

Jo-Bolt part no. (all head types)	Drill size	
	Col A	Col B
164	No. 42 (0.0935)	No. 23 (0.154)
200	No. 35 (0.110)	No. 12 (0.189)
260	No. 24 (0.152)	D (0.246)
312	No. 17 (0.173)	M (0.295)
375	No. 5 (0.2055)	$\frac{23}{64}$ (0.3594)

CHAPTER 8

FASTENERS

Section I. GENERAL

111. Fastening Devices

Various types of fastening devices allow quick dismantling or replacement of aircraft parts that must be taken apart and put back together at frequent intervals. Riveting or welding these parts each time they are serviced would weaken or ruin the joint. Furthermore, some joints require greater tensile strength and stiffness than rivets can provide. Bolts, turnlock fasteners, and structural screws are fastening devices which give the required security of attachment and rigidity. Bolts are used where great strength is required. Where strength is not so necessary, turnlock fasteners and structural screws are used. When it becomes necessary to replace aircraft fasteners, duplicate fasteners should be used if at all possible. If duplicate fasteners are unavailable, extreme care and caution must be exercised in making fastener substitution. When fastener substitution is necessary, it is advisable to obtain the services of a competent aeronautical engineer to assist in making the proper selection.

112. Bolts Versus Screws

An introduction to fasteners would not be com-

plete without a distinction being made between bolts and screws. They are similar in many ways. Both are pins or rods made of aluminum alloy or steel. They are used for fastening or holding, and each has a head on one end and screw threads on the other. Regardless of these similarities, there are several distinct differences between the two types of fasteners. They are as follows.

a. The threaded end of a screw may be either blunt or pointed, while that of a bolt is always blunt.

b. The threaded end of a bolt must have a nut screwed onto it to complete the assembly. The threaded end of a screw may fit into a female receptacle or it may fit directly into the metal being secured.

c. A bolt has a fairly short threaded section and a comparatively long grip length or unthreaded portion. The screw has a longer threaded section and no clearly defined grip length.

d. A bolt assembly is generally tightened by turning the nut on the bolt; the head of the bolt may or may not be designed for turning. A screw is always tightened by turning the head.

Section II. AIRCRAFT BOLTS

113. General

Aircraft bolts are fabricated from cadmium- or zinc-plated, corrosion-resistant steel, unplated corrosion-resistant steel, and anodized aluminum alloys. Most aircraft structural bolts are either general purpose hexagon head bolts, internal wrenching bolts, or close tolerance bolts. Aircraft manufacturers are sometimes compelled to make bolts of different dimensions or higher strength than the standard types. Since these bolts are made for a particular application, it is extremely important that like bolts be used for replacement. When such bolts are not available and it is necessary to fabricate them locally, care should be taken to use identical material and heat treatment specified in the applicable drawings or

an authorized substitute material properly heat treated. These special bolts are identified by the letter "S" stamped on the head.

114. Identification of Standard Bolts

Bolts are manufactured in many shapes and varieties. They may be classified by the shape of head, method of securing, and usage. The head shape may be hexagon, square, eye, or internal wrenching. From the standpoint of securing, they may be extension or key bolts. According to usage, they could be classified as carriage, machine, stove, or aircraft bolts. Unless otherwise stated, thread sizes on aircraft bolts are designated in National Fine (NF) readings.

a. *Bolthead Markings.* Bolts are designed and

fabricated of different materials and with different tensile strengths for their individual heat ranges and grip stresses. Each bolt is marked with a code for identification and physical characteristics. Refer to figure 186 for these code markings.

b. Part Number Designation. The bolt part number designation gives the type of bolt, diameter, material, length, length of grip, and states if head or shank is drilled. An example of the designation is AN3DD6A. AN signifies that the bolt is an Air Force-Navy standard design; 3 indicates 3/16-inch diameter; DD indicates 2024T aluminum alloy material; 6 indicates 25/32 inch long and 3/8-inch grip; and A indicates bolt is undrilled. The letter C in place of DD would indicate corrosion-resistant steel. The letter "H" in front of the number 6 would indicate bolthead and shank is drilled. The letter "H" in front of the dash number and the letter A after it indicates drilled head only. AN3DD6 indicates shank only is drilled; AN3DDH6 indicates head and shank are both drilled; and AN3DDH6A indicates only the head is drilled (fig. 187).

115. Grip Length

The grip length of a bolt is the length of the unthreaded portion of the bolt shank (between the head and threaded portion). Grip length is proportional to the length of the bolt and is usually included in the dash number of the coding number, which also incorporates the bolt length. In figure 187, note that bolt dash numbers are listed in the left-hand column, and that each dash number incorporates the same combination of bolt and grip lengths, regardless of the bolt thickness. When selecting a bolt for use, be sure that its grip length equals thickness of the material being bolted together, that no part of the threads bear on the material, and that the shank does not protrude too far through the nut. Since all these stipulations cannot always be met by a particular bolt, it may be desirable to select a bolt of slightly greater grip length than required and place a washer under the nut or bolthead. Where plate nuts are used, shims may be added under the plate.

116. Types

a. Hexagon Head Bolts. The common hexagon head aircraft bolt, AN3 through AN20, is an all-purpose structural bolt used for general applications involving tension as well as shear loads. It is made of cadmium or zinc-plated, noncorrosion-resistant steel, corrosion-resistant steel, or anodized aluminum alloy. Steel bolts smaller than AN3 and aluminum alloy bolts smaller than AN4 are easily overstressed at as-

sembly and are not used in primary structures. Hexagon head bolts are identified in figure 186.

b. Close Tolerance Bolts. Close tolerance hexagon head bolts, AN173 through AN186, and close tolerance 100-degree countersunk bolts, NAS334 through NAS340, are used in aircraft fabrication where bolted joints are subject to serve load reversals and vibration. The bolt shanks are made to close tolerance, permitting a very close fit with the use of reamers. The standard AN hexagon head bolts are otherwise identical and may be used for the same applications, provided a light-drive fit is accomplished. A light-drive fit may be considered as an interference fit of 0.0006 inch for a 5/8-inch diameter, other sizes are proportional. Use such bolts to eliminate loss of motion in control systems, etc. Close tolerance hexagon head bolts, AN173 through AN186, are identified in figure 187. Close tolerance 100-degree countersunk bolts are identified in figure 189. Use an internal hexagon, Phillips recess, or Frearson recess-type wrench for turning these 100-degree countersunk bolts.

c. Internal Wrenching Bolts. Internal wrenching bolts, MS20004 through MS20024 (fig. 190), are high-strength steel bolts used primarily in tension applications. For use in steel parts, the bolthead must be countersunk to seat the large corner radius of the shank at the head. For use in aluminum alloy, use MS20002C washer under the head to provide adequate bearing area. Use MS20002 plain washer under the nut. Do not substitute AN bolts or washers. Internal or external wrenching nuts only will be used with these bolts.

d. Drilled Head Bolts. The drilled hexagon head bolts, MS20073 and MS20074, are similar to the common hexagon head bolts, except they are machined to closer tolerances, their heads are drilled three ways and are somewhat deeper, and their thread length is slightly longer. Discrimination should be used when substituting AN3H through AN20H bolts (single-drilled hexagon heads). Hexagon head bolts, AN3 through AN12, and drilled hexagon head bolts, MS20073, are interchangeable in tensile and shear strengths. When used as capscrews and the parts are drawn tightly together, spring lockwashers may be used when specified. Drilled hexagon head bolts are identified in figure 188.

e. Clevis Bolts. Clevis bolts, AN21 through AN36, are used in applications subject to shearing stress and never in tension applications. They are often inserted as mechanical pins in control systems. The head is round and slotted. Clevis bolts are available in drilled or undrilled shanks (fig. 191).

f. *Eyebolts*. Eyebolts, AN42 through AN49 (fig. 192), are used where external tension loads are to be applied. The eye is designed for at-

tachment of such devices as the fork of a turn-buckle, a clevis, or a cable shackle. The threaded end may or may not be drilled for safetying.

MARKING	MATERIAL	PHYSICAL CHARACTERISTICS	CLASSIFICATION OR SPECIFICATION
1 	STEEL, LOW CARBON	YS: 60,000 PSI MIN	
	STEEL, COMMERCIAL	TS: 48,000 PSI MIN	BOLT, HEXAGON HEAD, FINE THREAD
3 	STEEL, COMMERCIAL	TS: 48,000 PSI MIN	BOLT, HEXAGON HEAD, COARSE THREAD
4 	STEEL, COMMERCIAL	TS: 48,000 PSI MIN	BOLT, CARRIAGE
5 	STEEL, LOW CARBON	TS: 70,000 PSI MIN RH: B80-100	AMS S061, COLD DRAWN
6 2 RADIAL DASHES, 180 DEGREES APART 	STEEL, MEDIUM CARBON	TS: 110,000 PSI MIN UP TO 1/2-INCH DIA INCLUSIVE RH: B95-104	SAE GRADE 3
		TS: 100,000 PSI MIN OVER 1/2-INCH AND UP TO 5/8-INCH DIA INCLUSIVE RH: B95-104	SAE GRADE 3
7 	STEEL, MEDIUM CARBON	YS: 75,000 PSI MIN	
8 3 RADIAL DASHES, 120 DEGREES APART 	STEEL, MEDIUM CARBON	TS: 120,000 PSI MIN UP TO 3/4-INCH DIA INCLUSIVE RH: C23-30 TS: 120,000 PSI MIN UP TO 3/4-INCH DIA INCLUSIVE RH: C23-32 TS: 110,000 PSI MIN OVER 3/4-INCH AND UP TO 1-INCH DIA INCLUSIVE RH: C19-30 TS: 115,000 PSI MIN OVER 3/4-INCH AND UP TO 1-INCH DIA INCLUSIVE RH: C22-32 TS: 105,000 PSI MIN OVER 1-INCH AND UP TO 1-1/2 INCH DIA INCLUSIVE RH: C19-30 TS: 90,000 PSI MIN OVER 1-1/2 INCH AND UP TO 2-1/2 INCH DIA INCLUSIVE RH: C9-21 TS: 90,000	GRADE 5 SAE GRADE 5, MIL-B-857 GRADE 5; AND ASTM A325 GRADE 5 SAE GRADE 5, MIL-B-857 GRADE 5; AND ASTM A325 SAE GRADE 5, MIL-B-857 GRADE 5; AND ASTM A325 GRADE 5 ASTM A325
9 4 RADIAL DASHES, 90 DEGREES APART 	STEEL, MEDIUM CARBON	TS: 140,000 PSI MIN UP TO 5/8-INCH DIA RH: C30-36 TS: 133,000 PSI MIN OVER 5/8-INCH AND UP TO 3/4-INCH DIA INCLUSIVE RH: C28-36	SAE GRADE 6 SAE GRADE 6
10 	STEEL, MEDIUM CARBON	YS: 95,000 PSI MIN	
11 5 RADIAL DASHES, 72 DEGREES APART 	STEEL, ALLOY, MEDIUM CARBON	TS: 130,000 PSI MIN RH: C28-34 TS: 133,000 PSI MIN UP TO 1-1/2 INCH DIA INCLUSIVE RH: C28-34	GRADE 7 SAE GRADE 7
12 6 RADIAL DASHES, 60 DEGREES APART 	STEEL, ALLOY, MEDIUM CARBON STEEL, ALLOY, QUENCHED AND TEMPERED STEEL, ALLOY, MEDIUM CARBON	TS: 150,000 PSI MIN UP TO 1-1/2 INCH DIA INCLUSIVE RH: C32-38 TS: 150,000 PSI MIN RH: C32-28 TS: 125,000 PSI MIN OVER 1-1/2 INCH AND UP TO 2-1/2 INCH DIA INCLUSIVE RH: C25 MIN	SAE GRADE 8 AND MIL-B-857 GRADE 8 ASTM A354, GRADE BD GRADE 8

Figure 186. Bolt and screw markings.

MARKING	MATERIAL	PHYSICAL CHARACTERISTICS	CLASSIFICATION OR SPECIFICATION
13 	STEEL, ALLOY, QUENCHED AND TEMPERED	TS: 105,000 PSI MIN UP TO 2-1/2 INCH DIA INCLUSIVE RH: C18-30 TS: 100,000 PSI MIN OVER 2-1/2 INCH AND UP TO 4-INCH DIA INCLUSIVE RH: C18-30	ASTM A354, GRADE BB ASTM A354, GRADE BB
14 	STEEL, ALLOY, QUENCHED AND TEMPERED	TS: 125,000 PSI MIN UP TO 2-1/2 INCH DIA INCLUSIVE RH: C25-34 TS: 115,000 PSI MIN OVER 2-1/2 INCH AND UP TO 4-INCH DIA INCLUSIVE RH: C25-34	ASTM A354, GRADE BC ASTM A354, GRADE BC
15 	STEEL, ALLOY	Y5: 130,000 PSI MIN	
16 	STEEL, ALLOY, MEDIUM CARBON	RH: C26-32	AMS 6320
17  WAS EL	STEEL, ALLOY, MEDIUM CARBON	RH: C26-32 (FOR HEXAGON HEAD BOLTS) RH: C32-36 (FOR SOCKET HEAD BOLTS)	AMS 6322
18 	STEEL, ALLOY, MEDIUM CARBON	RH: C26-32	AMS 6322
19 THREAD END 	STEEL, ALLOY, MEDIUM CARBON	RH: C32-36	AMS 6322
20 SINGLE X 	STEEL, ALLOY, MEDIUM CARBON (Cr, Ni, Mo)	TS: 125,000 PSI MIN RH: C26-32	MIL-B-6812 INCLUDES: MIL-5-5626 FOR NO. 4140 MIL-5-6049 FOR NO. 8740 MIL-5-6050 FOR NO. 8630 MIL-5-6098 FOR NO. 8735 MIL-5-6758 FOR NO. 4130 MIL-5-8695 FOR NO. 4037
21 	STEEL, ALLOY, MEDIUM CARBON (Cr, Ni, Mo)	TS: 125,000 PSI MIN RH: C26-32	MIL-5-7839 INCLUDES: MIL-5-6049 FOR NO. 8740 MIL-5-6050 FOR NO. 8630 MIL-5-6098 FOR NO. 8735 MIL-5-6758 FOR NO. 4130 MIL-5-8695 FOR NO. 4037
22 	STEEL, 5 PERCENT CHROMIUM	TS: 100,000 PSI MIN UP TO 2-1/2 INCH DIA IN- CLUSIVE TS: 95,000 PSI MIN OVER 2-1/2 INCH AND UP TO 4-INCH DIA INCLUSIVE	AISI 501, GRADE B5 (A193)
23 	STEEL, 12 PERCENT CHROMIUM	TS: 105,000 PSI MIN UP TO 2-1/2 INCH DIA INCLUSIVE TS: 100,000 PSI MIN OVER 2-1/2 INCH AND UP TO 4-INCH DIA INCLUSIVE	AISI 416, GRADE B6 (A193)
24 	STEEL, CHROMIUM- MOLYBDENUM	TS: 105,000 PSI MIN UP TO 2-1/2 INCH DIA IN- CLUSIVE TS: 105,000 PSI MIN OVER 2-1/2 INCH AND UP TO 4-INCH DIA INCLUSIVE TS: 90,000 PSI MIN OVER 4-INCH AND UP TO 7-INCH DIA INCLUSIVE	AISI 4140, 4142, AND 4145, GRADE B7 (A193)
25 	STEEL, CHROMIUM- HIGH-MOLYBDENUM	TS: 125,000 PSI MIN UP TO 2-1/2 INCH DIA INCLUSIVE TS: 115,000 PSI MIN OVER 2-1/2 INCH AND UP TO 4-INCH DIA INCLUSIVE	GRADE B7A (A193)
26 	STEEL, CHROMIUM- MOLYBDENUM- VANADIUM	TS: 125,000 PSI MIN UP TO 2-1/2 INCH DIA INCLUSIVE TS: 110,000 PSI MIN OVER 2-1/2 INCH AND UP TO 4-INCH DIA INCLUSIVE	GRADE B14 (A193)

Figure 186—Continued.

MARKING	MATERIAL	PHYSICAL CHARACTERISTICS	CLASSIFICATION OR SPECIFICATION
27 	STEEL, CHROMIUM - MOLYBDENUM- VANADIUM	TS: 125,000 PSI MIN UP TO 2-1/2 INCH DIA INCLUSIVE TS: 110,000 PSI MIN OVER 2-1/2 INCH AND UP TO 4-INCH DIA INCLUSIVE TS: 100,000 PSI MIN OVER 4-INCH AND UP TO 7-INCH DIA INCLUSIVE	GRADE B16 (A193)
28 2 RADIAL DASHES, 90 DEGREES APART 	STEEL, CORROSION- RESISTANT	TS: 75,000 PSI MIN	QQ-S-763, FS 303 CONDITION A
29 SINGLE DASH 	STEEL, CORROSION- RESISTANT (16Cr, 2Ni)		MIL-B-6812
30 (SINGLE DASH) — DR — (2 STAGGERED PARALLEL DASHES) 	STEEL, CORROSION- RESISTANT		NAS 380
31 	STEEL, CORROSION- RESISTANT	TS: 70,000 PSI MIN TS: 75,000 PSI MIN	NO. 410, HARDENED QQ-S-763 QQ-S-763, CLASS IV DR (18-8)
32 	STEEL, CORROSION- RESISTANT (18Cr, 8Ni)	CARBIDE TREATED TS: 75,000 PSI MIN ALL DIA ANNEALED TS: 75,000 PSI MIN ALL DIA COLD DRAWN TS: 125,000 PSI MIN UP TO 3/4-INCH DIA INCLUSIVE TS: 115,000 PSI MIN OVER 3/4-INCH AND UP TO 1-INCH DIA INCLUSIVE TS: 105,000 PSI MIN OVER 1-INCH AND UP TO 1-1/4 INCH DIA INCLUSIVE TS: 100,000 PSI MIN OVER 1-1/4 INCH AND UP TO 1-1/2 INCH DIA IN- CLUSIVE	AISI 304, GRADE B8 (A193) AISI 304, GRADE B8 (A320) AISI 304, GRADE B8 (A320)
33 	STEEL, CORROSION- RESISTANT (18Cr, 8Ni)	COLD DRAWN TS: 125,000 PSI MIN UP TO 3/4-INCH INCLUSIVE TS: 115,000 PSI MIN OVER 3/4-INCH AND UP TO 1-INCH DIA INCLUSIVE TS: 105,000 PSI MIN OVER 1-INCH AND UP TO 1-1/4 INCH DIA INCLUSIVE TS: 100,000 PSI MIN OVER 1-1/4 INCH AND UP TO 1-1/2 INCH DIA INCLUSIVE	AISI 304, GRADE B8 (A193)
34 	STEEL, CORROSION- RESISTANT	TS: 125,000 PSI MIN	AMS 7472 (17-20 Cr, 7-11Ni) DR AMS 5637, SAE 30302 (18Cr, 8Ni)
35 	STEEL, CORROSION- RESISTANT (18Cr, 8Ni, COLUMBIUM STABILIZED)	CARBIDE TREATED TS: 75,000 PSI MIN ALL DIA ANNEALED TS: 75,000 PSI MIN ALL DIA COLD DRAWN TS: 125,000 PSI MIN UP TO 3/4-INCH DIA INCLUSIVE TS: 115,000 PSI MIN OVER 3/4-INCH AND UP TO 1-INCH DIA INCLUSIVE TS: 105,000 PSI MIN OVER 1-INCH AND UP TO 1-1/4 INCH DIA INCLUSIVE TS: 100,000 PSI MIN OVER 1-1/4 INCH AND UP TO 1-1/2 INCH DIA INCLUSIVE	AISI 1347, GRADE B8C (A193) AISI 1347, GRADE 88C (A320)

Figure 186—Continued.

MARKING	MATERIAL	PHYSICAL CHARACTERISTICS	CLASSIFICATION OR SPECIFICATION
36 	STEEL, CORROSION-RESISTANT (18Cr, 8Ni, COLUMBIUM STABILIZED)	COLD DRAWN TS: 125,000 PSI MIN UP TO 3/4-INCH DIA INCLUSIVE TS: 115,000 PSI MIN OVER 3/4-INCH AND UP TO 1-INCH DIA INCLUSIVE TS: 105,000 PSI MIN OVER 1-INCH AND UP TO 1-1/4 INCH DIA INCLUSIVE TS: 100,000 PSI MIN OVER 1-1/4 INCH AND UP TO 1-1/2 INCH DIA INCLUSIVE	AISI 347, GRADE <u>B8C</u> (A193)
37 	STEEL, CORROSION-RESISTANT (18Cr, 8Ni, COLUMBIUM STABILIZED)	CARBIDE TREATED TS: 75,000 PSI MIN ALL DIA COLD DRAWN TS: 125,000 PSI MIN UP TO 3/4-INCH DIA INCLUSIVE TS: 115,000 PSI MIN OVER 3/4-INCH AND UP TO 1-INCH DIA INCLUSIVE TS: 105,000 PSI MIN OVER 1-INCH AND UP TO 1-1/4 INCH DIA INCLUSIVE TS: 100,000 PSI MIN OVER 1-1/4 INCH AND UP TO 1-1/2 INCH DIA INCLUSIVE ANNEALED TS: 75,000 PSI MIN ALL DIA	AISI 348, GRADE B8D (A193) AISI 348, GRADE B8D (A320) AISI 348, GRADE B8D (A320)
38 	STEEL, CORROSION-RESISTANT (18Cr, 8Ni, COLUMBIUM STABILIZED)	COLD DRAWN TS: 125,000 PSI MIN UP TO 3/4-INCH DIA INCLUSIVE TS: 115,000 PSI MIN OVER 3/4-INCH AND UP TO 1-INCH DIA INCLUSIVE TS: 105,000 PSI MIN OVER 1-INCH AND UP TO 1-1/4 INCH DIA INCLUSIVE TS: 100,000 PSI MIN OVER 1-1/4 INCH AND UP TO 1-1/2 INCH DIA INCLUSIVE	AISI 348, GRADE <u>B8D</u> (A193)
39 	STEEL, CORROSION-RESISTANT (18Cr, 8Ni, TITANIUM STABILIZED)	CARBIDE TREATED TS: 75,000 PSI MIN ALL DIA ANNEALED TS: 75,000 PSI MIN ALL DIA COLD DRAWN TS: 125,000 PSI MIN UP TO 3/4-INCH DIA INCLUSIVE TS: 115,000 PSI MIN OVER 3/4-INCH AND UP TO 1-INCH DIA INCLUSIVE TS: 105,000 PSI MIN OVER 1-INCH AND UP TO 1-1/4 INCH DIA INCLUSIVE TS: 100,000 PSI MIN OVER 1-1/4 INCH AND UP TO 1-1/2 INCH DIA INCLUSIVE	AISI 321, GRADE B8T (A193) AISI 321, GRADE B8T (A320) AISI 321, GRADE B8T (A320)
40 	STEEL, CORROSION-RESISTANT (18Cr, 8Ni, TITANIUM STABILIZED)	COLD DRAWN TS: 125,000 PSI MIN UP TO 3/4-INCH DIA INCLUSIVE TS: 115,000 PSI MIN OVER 3/4-INCH AND UP TO 1-INCH DIA INCLUSIVE TS: 105,000 PSI MIN OVER 1-INCH AND UP TO 1-1/4 INCH DIA INCLUSIVE TS: 100,000 PSI MIN OVER 1-1/4 INCH AND UP TO 1-1/2 INCH DIA INCLUSIVE	AISI 321, GRADE <u>B8T</u> (A320)
41 	STEEL, CORROSION-RESISTANT (18Cr, 8Ni, FREE MACHINING)	CARBIDE TREATED TS: 75,000 PSI MIN ALL DIA ANNEALED TS: 75,000 PSI MIN ALL DIA COLD DRAWN TS: 125,000 PSI MIN UP TO 3/4-INCH DIA INCLUSIVE TS: 115,000 PSI MIN OVER 3/4-INCH AND UP TO 1-INCH DIA INCLUSIVE TS: 105,000 PSI MIN OVER 1-INCH AND UP TO 1-1/4 INCH DIA INCLUSIVE TS: 100,000 PSI MIN OVER 1-1/4 INCH AND UP TO 1-1/2 INCH DIA INCLUSIVE	AISI 303, GRADE B8F (A193) AISI 303, GRADE B8F (A320) AISI 303, GRADE B8F (A320)

Figure 186—Continued.

MARKING	MATERIAL	PHYSICAL CHARACTERISTICS	CLASSIFICATION OR SPECIFICATION
42 	STEEL, CORROSION-RESISTANT (18Cr, 8Ni, FREE MACHINING)	COLD DRAWN TS: 125,000 PSI MIN UP TO 3/4-INCH DIA INCLUSIVE TS: 115,000 PSI MIN OVER 3/4-INCH AND UP TO 1-INCH DIA INCLUSIVE TS: 105,000 PSI MIN OVER 1-INCH AND UP TO 1-1/4 INCH DIA INCLUSIVE TS: 100,000 PSI MIN OVER 1-1/4 INCH AND UP TO 1-1/2 INCH DIA INCLUSIVE	AISI 303, GRADE <u>B8F</u> (A193)
43 	STEEL, CORROSION-AND HEAT-RESISTANT (15Cr, 26Ni, 1.3Mo, 1.9Ti, 0.3V)	TS: 130,000 PSI MIN BH: 248 TO 321	AMS 5735
44 	STEEL, CORROSION-AND HEAT-RESISTANT	TS: 110,000 PSI MIN	MIL-B-7874, 1200-F
45 	STEEL, CHROMIUM, MOLYBDENUM	TS: 125,000 PSI MIN UP TO 2-1/2 INCH DIA INCLUSIVE TS: 105,000 PSI MIN OVER 2-1/2 INCH AND UP TO 4-INCH DIA INCLUSIVE	AISI 4140, 4142, AND 4145, GRADE L7 (A320)
46 	STEEL, NICKEL	TS: 125,000 PSI MIN UP TO 2-1/2 INCH DIA INCLUSIVE TS: 105,000 PSI MIN OVER 2-1/2 INCH AND UP TO 4-INCH DIA INCLUSIVE	AISI 2340, GRADE L9 (A320)
47 	STEEL, NICKEL	TS: 70,000 PSI MIN UP TO 4-INCH DIA INCLUSIVE	AISI 2317, GRADE L10 (A320)
48 	STEEL, NICKEL-CHROMIUM-MOLYBDENUM	TS: 125,000 PSI MIN UP TO 4-INCH DIA INCLUSIVE	AISI 4340, GRADE L43 (A320)
49 	ALLOY STEEL	125,000 TO 145,000 PSI	NAS380
50 		CLOSE TOLERANCE CLOSE TOLERANCE SHANK AND/OR HEAD	NAS380
51 TRIANGLE WITH A DIMPLE 		CLOSE TOLERANCE SHANK AND/OR HEAD, HIGH STRENGTH 160,000 TO 180,000 PSI	NAS380
52 TRIANGLE WITH AN X INSIDE 	ALLOY STEEL	CLOSE TOLERANCE SHANK AND/OR HEAD, 125,000 TO 145,000 PSI	NAS380
53 R		ROLLED THREADS AFTER HEAT TREATMENT	NAS380
54 	ALUMINUM ALLOY	TS: 62,000 PSI MIN	NAS380 MIL-B-6812 (AL-24)
55 	BRONZE, COMMERCIAL	TS: 85,000 PSI MIN	NAS380

*MARKING FOR CORROSION-RESISTANT STEEL SCREWS. ONLY ONE VISIBLE DASH NECESSARY AFTER SLOTTING OPERATIONS. POSITION IS OPTIONAL. NO MARKINGS REQUIRED ON HEADS OF SIZES NUMBER 4 OR SMALLER.

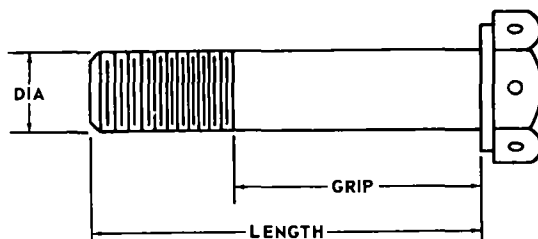
Figure 186—Continued.



BOLT SIZE		AN173 (10-32)	AN174 (1/4-28)	AN175 (5/16-24)	AN176 (3/8-24)	AN177 (7/16-20)	AN178 (1/2-20)	AN179 (9/16-18)	AN180 (5/8-18)	AN182 (3/4-16)	AN184 (7/8-14)	AN186 (1-14)	
B		0.375	0.438	0.500	0.563	0.625	0.750	0.875	0.938	1.063	1.250	1.438	
E		1/8	5/32	3/16	7/32	1/4	9/32	5/16	11/32	13/32	15/32	17/32	
SHANK DIAMETER		+0.0000 0.1894 -0.0005	+0.0000 0.2492 -0.0005	+0.0000 0.3117 -0.0005	+0.0000 0.3742 -0.0005	+0.0000 0.4367 -0.0005	+0.0000 0.4991 -0.0005	+0.0000 0.5616 -0.0005	+0.0000 0.6240 -0.0006	+0.0000 0.7488 -0.0007	+0.0000 0.8737 -0.0008	+0.0000 0.9985 -0.0010	
DRILL DIAMETER	HEAD	NO. 56 (0.046)	NO. 56 (0.046)	NO. 50 (0.070)	NO. 50 (0.070)	NO. 50 (0.070)	NO. 50 (0.070)	NO. 50 (0.070)	NO. 50 (0.070)	NO. 50 (0.070)	NO. 50 (0.070)	NO. 50 (0.070)	
	COTTER	NO. 50 (0.070)	NO. 48 (0.076)	NO. 48 (0.076)	NO. 36 (0.106)	NO. 36 (0.106)	NO. 36 (0.106)	NO. 28 (0.141)	NO. 28 (0.141)	NO. 28 (0.141)	NO. 28 (0.141)	NO. 28 (0.141)	
STEEL BOLTS	TENSILE STRENGTH (LB)	2210	4080	6500	10100	13600	18500	23600	30100	44000	60000	80700	
	SHEAR STRENGTH	2125	3680	5750	8280	11250	14700	18700	23000	33150	45050	58900	
2024 ALLOY BOLTS	TENSILE STRENGTH (LB)	1100	2030	3220	5020	6750	9180	11700	14900	21800	29800	40000	
	SHEAR STRENGTH	990	1715	2685	3870	5250	6850	8700	10750	15500	21050	27500	
DASH NUMBERS (SEE NOTE 1.)		L	G	L	G	L	G	L	G	L	G	L	G
-3		15/32	1/16	15/32	1/16								
-4		17/32	1/8	17/32	1/16	19/32	1/16						
-5		21/32	1/4	21/32	3/16	23/32	3/16	45/64	1/16	23/32	1/16		
-6		25/32	3/8	25/32	5/16	27/32	5/16	53/64	3/16	27/32	3/16	27/32	1/16
-7		29/32	1/2	29/32	7/16	31/32	7/16	61/64	5/16	31/32	5/16	31/32	3/16
-10		1-1/32	5/8	1-1/32	9/16	1-3/32	9/16	1-5/64	7/16	1-3/32	7/16	1-3/32	5/16
-11		1-5/32	3/4	1-5/32	11/16	1-7/32	11/16	1-13/64	9/16	1-7/32	9/16	1-7/32	7/16
-12		1-9/32	7/8	1-9/32	13/16	1-11/32	13/16	1-21/64	11/16	1-11/32	11/16	1-11/32	9/16
-13		1-13/32	1	1-13/32	15/16	1-15/32	15/16	1-29/64	13/16	1-15/32	13/16	1-15/32	11/16
-14		1-17/32	1-1/8	1-17/32	1-1/16	1-19/32	1-1/16	1-37/64	15/16	1-19/32	15/16	1-19/32	13/16
-15		1-21/32	1-1/4	1-21/32	1-3/16	1-23/32	1-3/16	1-45/64	1-1/16	1-23/32	1-1/16	1-23/32	15/16
-16		1-25/32	1-3/8	1-25/32	1-5/16	1-27/32	1-5/16	1-53/64	1-3/16	1-27/32	1-3/16	1-27/32	1-1/16
-17		1-29/32	1-1/2	1-29/32	1-7/16	1-31/32	1-7/16	1-61/64	1-5/16	1-31/32	1-5/16	1-31/32	1-3/16
-20		2-1/32	1-5/8	2-1/32	1-9/16	2-3/32	1-9/16	2-5/64	1-7/16	2-3/32	1-7/16	2-3/32	1-5/16

NOTES: 1. FOR BOLTS OF LONGER GRIP AND LENGTH (-21 THROUGH -80) REFER TO AN AERONAUTICAL STANDARD DRAWINGS.
2. DIMENSIONS SHOWN ARE IN INCHES.

Figure 187. Close tolerance hexagon head bolts.



MS NUMBERS	MS20073	MS20074	MS20073	MS20074	MS20073	MS20074	MS20073	MS20074	MS20073	MS20074
SIZE AND THREAD	NO. 10-32	NO. 10-24	1/4-28	1/4-20	5/16-24	5/16-18	3/8-24	3/8-16	7/16-20	7/16-14
DIAMETER	+0.000 0.189 -0.003		+0.000 0.249 -0.003		+0.000 0.312 -0.003		+0.000 0.374 -0.003		+0.000 0.437 -0.004	
TENSILE STRENGTH (LB) (SEE NOTE 1.)	2210	1800	4080	3360	6500	5660	10100	8470	13600	11680
SHEAR STRENGTH (LB)	2125	2125	3680	3680	5750	5750	8800	8800	11250	11250
MS NUMBERS	MS20073	MS20074	MS20073	MS20074	MS20073	MS20074	MS20073	MS20074		
THREAD	1/2-20	1/2-13	9/16-18	9/16-12	5/8-18	5/8-11	3/4-16	3/4-10		
DIAMETER	+0.000 0.499 -0.004		+0.000 0.562 -0.004		+0.000 0.624 -0.004		+0.000 0.749 -0.005			
TENSILE STRENGTH (LB) (SEE NOTE 1.)	18500	15730	23600	20300	30100	25100	44000	37800		
SHEAR STRENGTH (LB)	14700	14700	18700	18700	23000	23000	33150	33150		

NOTES:

1. YIELD STRENGTH = 76.7 PERCENT RATED TENSION.

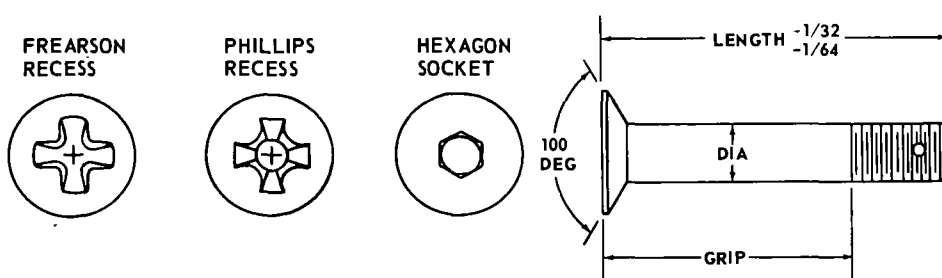
2. EXAMPLES OF PART NUMBERS:

MS20073-05-07 = 5/16-24 UNF-3A BOLT, 0.375-INCH GRIP, 0.922-INCH LENGTH.
MS20074-05-07 = 5/16-18 UNC-3A BOLT, 0.375-INCH GRIP, 0.922-INCH LENGTH.

3. MATERIAL: 2330 STEEL OR EQUIVALENT.

4. DIMENSIONS SHOWN ARE IN INCHES.

Figure 188. Drilled hexagon head bolts.



NAS NUMBERS	NAS334	NAS335	NAS336	NAS337	NAS338	NAS339	NAS340
SIZE AND THREAD	1/4-28	5/16-24	3/8-24	7/16-20	1/2-20	9/16-18	5/8-18
DIAMETER	+0.0000 0.2492 -0.0005	+0.0000 0.3117 -0.0005	+0.0000 0.3742 -0.0005	+0.0000 0.4367 -0.0005	+0.0000 0.4991 -0.0005	+0.0000 0.5616 -0.0005	+0.0000 0.6240 -0.0006
TENSILE STRENGTH (LB)	4080	6500	10100	13600	18500	23600	30100
SHEAR STRENGTH (LB)	3680	5750	8280	11250	14700	18700	23000

NOTES:

1. EXAMPLES OF PART NUMBERS:

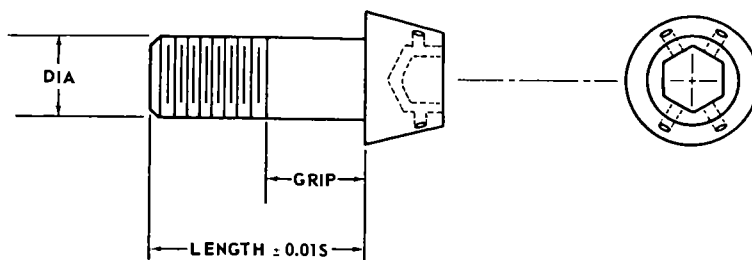
NAS334-23 = BOLT, 1-15/16 INCH GRIP, 2-13/32 INCH LENGTH, DRILLED.

NAS334-23A = BOLT, 1-15/16 INCH GRIP, 2-13/32 INCH LENGTH, UNDRILLED.

2. MATERIAL: 2330 NICKEL STEEL

3. DIMENSIONS SHOWN ARE IN INCHES.

Figure 189. Close tolerance 100-degree countersunk bolts.



MS NUMBERS	MS20004	MS20005	MS20006	MS20007	MS20008	MS20009		
SIZE AND THREAD	1/4-28	5/16-24	3/8-24	7/16-20	1/2-20	9/16-18		
DIAMETER	0.2492 0.2477	0.3117 0.3102	0.3742 0.3727	0.4367 0.4347	0.4991 0.4971	0.5616 0.5596		
TENSILE STRENGTH (LB)	5000	8200	12700	17100	23400	29800		
SHEAR STRENGTH (LB) (SEE NOTE 1.)	4650	7300	10500	14300	18650	23600		
MS NUMBERS	MS20010	MS20012	MS20014	MS20016	MS20018	MS20020	MS20022	MS20024
SIZE AND THREAD	5/8-18	3/4-16	7/8-14	1-14	1-1/8-12	1-1/4-12	1-3/8-12	1-1/2-12
DIAMETER	0.6240 0.6220	0.7488 0.7468	0.8737 0.8707	0.9985 0.9955	1.124 1.121	1.249 1.246	1.374 1.370	1.499 1.495
TENSILE STRENGTH (LB)	38000	55600	76200	102500	128800	162600	200300	241600
SHEAR STRENGTH (LB)	29150	41950	57100	74600	94450	116600	141050	167900

NOTES:

1. SHEAR STRENGTH BASED ON 95,000 PSI.

2. EXAMPLES OF PART NUMBERS:

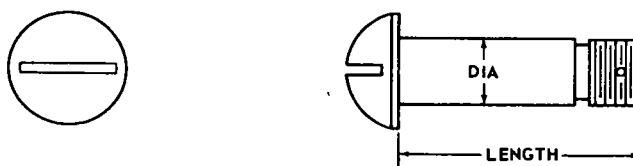
MS20005-25 = BOLT, 1-9/16 INCH LENGTH, NOT DRILLED.

MS20005DH25 = BOLT, 1-9/16 INCH LENGTH, DRILLED HEAD.

3. MATERIAL: 2330 OR 4130, STEEL, OR EQUIVALENT, MINIMUM ELONGATION 12 PERCENT, HEAT-TREAT TO OBTAIN 160,000 TO 180,000 PSI TENSILE STRENGTH.

4. DIMENSIONS SHOWN ARE IN INCHES.

Figure 190. Internal wrenching bolts.



AN NUMBERS	AN21	AN22	AN23	AN24	AN25	AN26	AN27	AN28	AN29	AN30	AN32	AN34	AN36
SIZE AND THREAD	NO. 6-40	NO. 8-36	NO. 10-32	1/4-28	5/16-24	3/8-24	7/16-20	1/2-20	9/16-18	5/8-18	3/4-16	7/8-14	1-14
DIAMETER	0.136	0.162	0.186	0.248	0.311	0.373	0.436	0.497	0.560	0.622	0.747	0.871	0.996
TENSILE STRENGTH (LB) (SEE NOTE 1.)	510	760	1105	2040	3250	5050	6800	9250	11800	15050	22000	30000	40350
SHEAR STRENGTH (LB)	1060	1500	2125	3680	5750	8280	11250	14700	18700	23000	33150	45050	58900

NOTES:

1. RATED TENSION STRENGTH APPLICABLE ONLY WHEN SHEAR NUT AN320 OR MS20364 IS USED.

2. ADD A AFTER DASH NUMBER FOR UNDRILLED BOLT.

3. EXAMPLES OF PART NUMBERS:

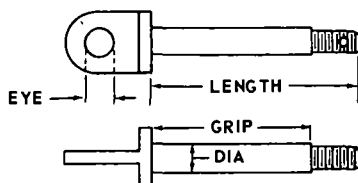
AN23-8 = NO. 10 BOLT, 17/32-INCH LENGTH, WITH COTTER PIN HOLE.

AN23-8A = NO. 10 BOLT, 17/32-INCH LENGTH, WITHOUT COTTER PIN HOLE.

4. MATERIAL: 2330 STEEL OR EQUIVALENT

5. DIMENSIONS SHOWN ARE IN INCHES.

Figure 191. Clevis bolts.



AN NUMBERS	AN42B	AN43B	AN44	AN45	AN46	AN47	AN48	AN49
SIZE AND THREAD	NO. 10-32	1/4-28	5/16-24	5/16-24	3/8-24	7/16-20	1/2-20	9/16-18
DIAMETER	0.189 0.186	0.249 0.246	0.312 0.309	0.312 0.309	0.374 0.371	0.437 0.433	0.499 0.495	0.562 0.558
EYE	0.192 0.190	0.192 0.190	0.253 0.250	0.316 0.313	0.378 0.375	0.378 0.375	0.441 0.438	0.503 0.500
TENSILE STRENGTH OF EYE (LB)	1150	2450	3910	5290	7015	9200	14375	20125
YIELD STRENGTH OF EYE (LB)	880	1880	3000	4055	5375	7055	11020	15430

NOTES:

1. ADD A AFTER DASH NUMBER FOR BOLTS WITHOUT HOLE DRILLED IN SHANK.

2. ADD C BEFORE DASH NUMBER FOR CORROSION-RESISTANT STEEL BOLT.

3. EXAMPLES OF PART NUMBERS:

AN46-10 = 3/8-24 NONCORROSION-RESISTANT STEEL EYEBOLT, 1-5/64 INCH LENGTH, HAVING 7/16-INCH GRIP, AND WITH HOLE DRILLED IN SHANK.

AN46-10A = 3/8-24 NONCORROSION-RESISTANT STEEL EYEBOLT, 1-5/64 INCH LENGTH, HAVING 7/16-INCH GRIP, AND WITHOUT HOLE DRILLED IN SHANK.

AN46C10 = 3/8-24 CORROSION-RESISTANT STEEL EYEBOLT, 1-5/64 INCH LENGTH, HAVING 7/16-INCH GRIP, AND WITH HOLE DRILLED IN SHANK.

AN46C10A = 3/8-24 CORROSION-RESISTANT STEEL EYEBOLT, 1-5/64 INCH LENGTH, HAVING 7/16-INCH GRIP, AND WITHOUT HOLE DRILLED IN SHANK.

AN43BC10A = 1/4-28 CORROSION-RESISTANT STEEL EYEBOLT, 1-1/32 INCH LENGTH, HAVING 9/16-INCH GRIP, AND WITHOUT HOLE DRILLED IN SHANK.

4. MATERIAL: 2330 STEEL OR EQUIVALENT.

5. DIMENSIONS SHOWN ARE IN INCHES.

Figure 192. Eyebolts.

Section III AIRCRAFT NUTS

117. Identification and Coding

a. Identification.

(1) Aircraft nuts are made in a variety of shapes and sizes. They are made of cadmium-plated carbon steel, corrosion resistant steel, brass, or anodized 2024T aluminum alloy, and may be obtained with right- or left-hand threads.

(2) Nuts do not come with the bolts when bolts are ordered; they come separately and must be ordered separately. No identifying marking or lettering appears on nuts. They can be identified only by the characteristic metallic luster or color of the aluminum, brass, or fiber, or by their construction or thread size.

(3) Except for a few very special types, nearly all aircraft nuts are Army-Navy standard. In stock lists, part numbers designate the type of nut. The common types and the respective part numbers are plain, AN315 and AN335; castle, AN310; plain check, AN316; light hexagon, AN340 and AN345; and castellated shear, AN320. The patented self-locking types are assigned part numbers ranging from MS20363

through MS20367. Part number AN350 is assigned to the wingnut.

b. Coding.

(1) Letters and digits following the part number indicate such items as material, size, threads per inch, and right- or left-hand threads. The letter B following the part number indicates nut material to be brass; a D, 2017T aluminum alloy; a DD, 2024T aluminum alloy; a C, stainless steel; and a dash in place of a letter indicates material to be cadmium-plated carbon steel.

(2) The digit, or two digits, following the dash or the material code letter represents the dash number of the nut, and indicates size of the shank and threads per inch of the bolt on which the nut will fit. The dash number corresponds to the first figure appearing in the part number coding of general purpose bolts. A dash number 3, for example, indicates the nut will fit an AN3 bolt (10-32); a 4 means it will fit an AN4 bolt (1/4-28); a 5, an AN5 bolt (5/16-24); and so on.

(3) The code numbers for self-locking nuts end in three- or four-digit numbers. The last two digits refer to threads per inch, and the one or two digits preceding these two digits stand for the nut size in sixteenths of an inch.

(4) Consider an example of the code numbers used to order aircraft nuts. Suppose a nut is needed to fit a 1/4-inch bolt. A corrosion resistant steel, plain nut of 28 threads per inch is required. Also needed is a corrosion resistant check-nut. Both are to have right-hand threads. Determine the code number to be used in ordering these nuts as follows:

AN315 or AN335 = plain nut part number
 4 (1/16) = 1/4-inch screw and thread size
 C = stainless steel (corrosion-resisting)
 R = right-hand thread

The complete code number for ordering the plain nut would be AN315C4R.

AN316 = plain checknut part number
 4 (1/16) = 1/4-inch screw and thread size
 C = stainless steel (corrosion-resisting)
 R = right-hand thread

The complete code number for ordering the plain checknut would be AN316C4R.

(5) Some other common nuts and their code numbers are given in the following examples:

(a) *Code number AN310DD5R.*

AN310 = aircraft castle nut
 DD = 2024T aluminum alloy
 5 = 5/16 inch in diameter
 R = right-hand thread (usually 24 threads per inch)

(b) *Code number AN320-10.*

AN320 = aircraft castellated shear nut
 dash (-) = cadmium-plated carbon steel
 10 = 10 inch in diameter (usually right-hand thread, 18 threads per inch)

(c) *Code number AN350B1032.*

AN350 = aircraft wingnut
 B = brass
 10 = number 10 bolt
 32 = threads per inch

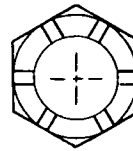
118. Types and Applications

Aircraft nuts may be divided into two general groups: nonself-locking nuts, which must be safetied by external-locking devices such as lock-nuts, cotterpins, or safety wire; and self-locking nuts, which contain the locking feature as an integral part.

a. Nonself-Locking Nuts.

(1) *Castellated nuts.* Airframe castellated nuts, AN310 (fig. 193), are used in conjunction with drilled-shank AN hexagon head bolts, clevis bolts, eyebolts, drilled head bolts, or studs. It is fairly rugged and can withstand large tensional loads. Slots, called castellations, in the nuts are designed to accommodate a cotterpin or lock wire for safetying purposes.

(2) *Castle shear nuts.* Aircraft castle shear nuts, AN320 (fig. 194), are designed for use with devices such as drilled clevis bolts and threaded taper pins which are normally sub-



PART NUMBERS		SIZE AND THREAD (NF-3)
STEEL	ALUMINUM ALLOY	
AN310-3	AN310D3	NO. 10-32
AN310-4	AN310D4	1/4-28
AN310-5	AN310D5	5/16-24
AN310-6	AN310D6	3/8-24
AN310-7	AN310D7	7/16-20
AN310-8	AN310D8	1/2-20
AN310-9	AN310D9	9/16-18
AN310-10	AN310D10	5/8-18
AN310-12	AN310D12	3/4-16
AN310-14	AN310D14	7/8-14
AN310-16	AN310D16	1-14
AN310-18	AN310D18	1-1/8-12
AN310-20	AN310D20	1-1/4-12

NOTES:

1. ADD C BEFORE OASH NUMBER FOR CORROSION-RESISTANT STEEL NUTS.

2. EXAMPLES OF PART NUMBERS:

AN310-5 = 5/16-24 STEEL NUT
 AN310D5 = 5/16-24 ALUMINUM ALLOY NUT.
 AN310C5 = 5/16-24 CORROSION-RESISTANT STEEL NUT.

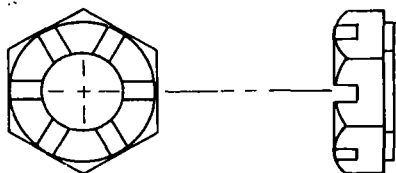
3. DIMENSIONS SHOWN ARE IN INCHES.

Figure 193. AN310 castellated nuts.

jected to shearing stress only. Like the castellated nut, the castle shear nut is castellated for safetying. Note, however, that the castle shear nut is not as deep or as strong as the castellated nut; also, the castellations are not as deep.

(3) *Plain hexagon nuts.* The plain hexagon nuts, AN315 fine thread (fig. 195), and AN335 coarse thread (fig. 196), are of rugged construction. This makes them suitable for carrying large tensional loads. As these nuts require an auxiliary locking device such as a checknut or lock-washer, their use on aircraft structure is somewhat limited.

(4) *Light hexagon nuts.* The light hexagon nuts, AN340 coarse thread (fig. 197), and AN345 fine thread (fig. 198), are much lighter nuts than the plain hexagon nuts and must be locked by an auxiliary device. These nuts are



ROUND OR SQUARE
BOTTOM CASTELLATION OPTIONAL

PART NUMBERS		SIZE AND THREAD (NF-3)
STEEL	ALUMINUM ALLOY	
AN320-1	AN320D1	NO. 6-40
AN320-2	AN320D2	NO. 8-36
AN320-3	AN320D3	NO. 10-32
AN320-4	AN320D4	1/4-28
AN320-5	AN320D5	5/16-24
AN320-6	AN320D6	3/8-24
AN320-7	AN320D7	7/16-20
AN320-8	AN320D8	1/2-20
AN320-9	AN320D9	9/16-18
AN320-10	AN320D10	5/8-18
AN320-12	AN320D12	3/4-16
AN320-14	AN320D14	7/8-14
AN320-16	AN320D16	1-14
AN320-18	AN320D18	1-1/8-12
AN320-20	AN320D20	1-1/4-12

NOTES:

1. ADD C BEFORE DASH NUMBER FOR CORROSION-RESISTANT STEEL NUTS.
2. EXAMPLES OF PART NUMBERS:
AN320-7 = 7/16-20 STEEL NUT
AN320D7 = 7/16-20 ALUMINUM ALLOY NUT
AN320C7 = 7/16-20 CORROSION-RESISTANT STEEL NUT.
3. DIMENSIONS SHOWN ARE IN INCHES.

Figure 194. Castle shear nuts.

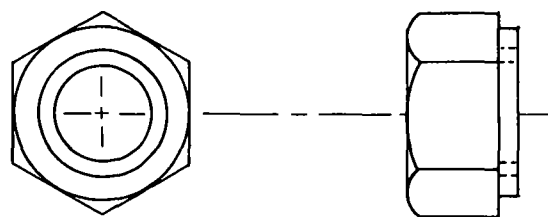
used for miscellaneous light-tension requirements. Use light hexagon nuts, MS20341, for electrical connections.

(5) *Plain checknuts.* Aircraft plain checknuts, AN316 (fig. 199), are employed as locking devices for plain nuts, setscrews, threaded rod ends, and other similar items.

(6) *Wingnuts.* Wingnuts, AN350 (fig. 200), are used where desired tightness is ordinarily obtained by use of the fingers, and where the assembly is removed frequently. The plain wingnut requires lock wire as an auxiliary locking device; the self-locking wingnut, W002, does not. Wingnuts may be used to fasten hose clamps and battery connections.

b. *Self-Locking Nuts.*

(1) *Metallic and nonmetallic insert nuts.* The two general types of self-locking nuts currently in use are designated as the all-metal type and the nonmetallic-insert (fiber or nylon) type. Each obtains its locking quality through a dif-



PART NUMBERS				SIZE AND THREAD (NF-3)
STEEL		ALUMINUM ALLOY		
LH THREAD	RH THREAD	LH THREAD	RH THREAD	
AN315-640L	-640R	AN315D640L	-D640R	NO. 6-40
AN315-3L	-3R	AN315D3L	-D3R	NO. 10-32
AN315-4L	-4R	AN315D4L	-D4R	1/4-28
AN315-5L	-5R	AN315D5L	-D5R	5/16-24
AN315-6L	-6R	AN315D6L	-D6R	3/8-24
AN315-7L	-7R	AN315D7L	-D7R	7/16-20
AN315-8L	-8R	AN315D8L	-D8R	1/2-20
AN315-9L	-9R	AN315D9L	-D9R	9/16-18
AN315-10L	-10R	AN315D10L	-D10R	5/8-18
AN315-12L	-12R	AN315D12L	-D12R	3/4-16
AN315-14L	-14R	AN315D14L	-D14R	7/8-14
AN315-16L	-16R	AN315D16L	-D16R	1-14
AN315-18L	-18R	AN315D18L	-D18R	1-1/8-12
AN315-20L	-20R	AN315D20L	-D20R	1-1/4-12

NOTES:

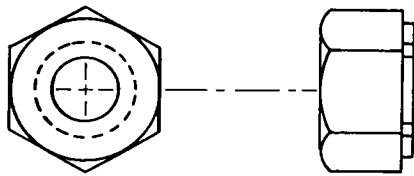
1. ADD C BEFORE DASH NUMBER FOR CORROSION-RESISTANT STEEL NUTS.
2. EXAMPLES OF PART NUMBERS:
AN315-7L = 7/16-20 STEEL NUT, LEFT-HAND THREAD.
AN315D7R = 7/16-20 ALUMINUM ALLOY NUT, RIGHT-HAND THREAD
AN315C7R = 7/16-20 CORROSION-RESISTANT STEEL NUT, RIGHT-HAND THREAD.
3. DIMENSIONS SHOWN ARE IN INCHES.

Figure 195. AN315 plain hexagon nuts, fine thread.

ferent means as indicated by its respective title. Standard all-metal and nonmetallic self-locking nuts are shown in figures 201 and 202.

(a) *Metallic self-locking nuts.* The all-metal, self-locking nuts depend upon the ability of the metal to recover its size and shape when the locking action and the loadcarrying portion are engaged by bolt or screw threads. This nut will hold tight in spite of severe vibration and can be used several times before it has to be replaced. High temperature, AN363 or approved equivalent, and cadmium plated, all-metal, self-locking nuts will not be subjected to temperatures in excess of 550°. (288°C.).

(b) *Nonmetallic-insert, self-locking nuts.* The nonmetallic-insert, self-locking nuts depend upon fiber or nylon inserts pressed within the inside diameter of the nut for their locking action. When a screw or bolt is installed, the insert stretches and forces contact between itself and



PART NUMBERS		SIZE AND THREAD (NC-2)
STEEL	BRASS	
AN335-4	AN335B4	1/4-20
AN335-5	AN335B5	5/16-18
AN335-6	AN335B6	3/8-16
AN335-7	AN335B7	7/16-14
AN335-8	AN335B8	1/2-13
AN335-10	AN335B10	5/8-11
AN335-12	AN335B12	3/4-10
AN335-14	AN335B14	7/8-9
AN335-16	AN335B16	1-8

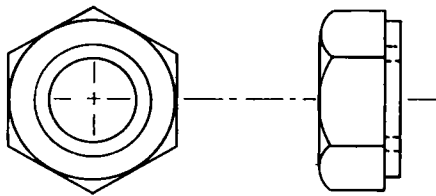
NOTES:

1. EXAMPLES OF PART NUMBERS:

AN335-4 = 1/4-20 STEEL NUT.
AN335B4 = 1/4-20 BRASS NUT.

2. DIMENSIONS SHOWN ARE IN INCHES.

Figure 196. AN335 plain hexagon nuts, coarse thread.



PART NUMBERS FOR ALLOY STEEL	SIZE AND THREAD (NC-2)
AN340-2	NO. 2-56
AN340-3	NO. 3-48
AN340-4	NO. 4-40
AN340-5	NO. 5-40
AN340-6	NO. 6-32
AN340-8	NO. 8-32

NOTES:

1. ADD B BEFORE DASH NUMBER FOR BRASS NUTS.

2. ADD C BEFORE DASH NUMBER FOR CORROSION-RESISTANT STEEL NUTS.

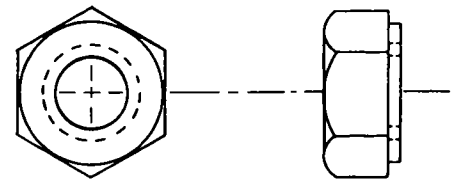
3. EXAMPLES OF PART NUMBERS:

AN340-2 = NO. 2-56 ALLOY STEEL NUT.
AN340C2 = NO. 2-56 CORROSION-RESISTANT STEEL NUT.
AN340B2 = NO. 2-56 BRASS NUT

4. DIMENSIONS SHOWN ARE IN INCHES

Figure 197. AN340 light hexagon nuts, coarse thread.

the bolt or screw threads, producing the locking action. Bolts, studs, or screws of 5/16-inch diameter and over, with cotter pinholes, may be used with nonmetallic-insert, self-locking nuts,



PART NUMBERS FOR ALLOY STEEL	SIZE AND THREAD
AN345-0	NO. 0-80 NF-2B
AN345-10	NO. 10-32 NF-2B
AN345-416	1/4-28 UNF-2B
AN345-516	5/16-24 UNF-2B
AN345-616	3/8-24 UNF-2B

NOTES:

1. ADD B BEFORE DASH NUMBER FOR BRASS NUTS.

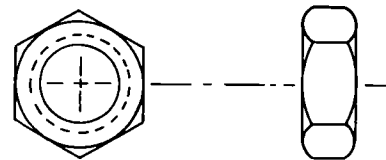
2. ADD C BEFORE DASH NUMBER FOR CORROSION-RESISTANT STEEL NUTS

3. EXAMPLES OF PART NUMBERS:

AN345-416 = 1/4-28 ALLOY STEEL NUT.
AN345C416 = 1/4-28 CORROSION-RESISTANT STEEL NUT.
AN345B416 = 1/4-28 BRASS NUT.

4. DIMENSIONS SHOWN ARE IN INCHES.

Figure 198. AN345 light hexagon nuts, fine thread.



PART NUMBER LH THREAD	PART NUMBER RH THREAD	SIZE AND THREAD (NF-3)
AN316-4L	-4R	1/4-28
AN316-5L	-5R	5/16-24
AN316-6L	-6R	3/8-24
AN316-7L	-7R	7/16-20
AN316-8L	-8R	1/2-20
AN316-9L	-9R	9/16-18
AN316-10L	-10R	5/8-18
AN316-12L	-12R	3/4-16
AN316-14L	-14R	7/8-14
AN316-16L	-16R	1-14

NOTES:

1. ADD C BEFORE DASH NUMBER FOR CORROSION-RESISTANT STEEL NUTS.

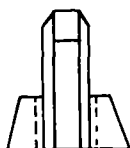
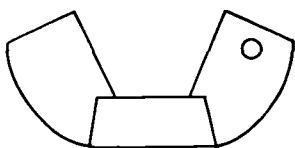
2. EXAMPLES OF PART NUMBERS:

AN316-7R = 7/16-20 STEEL NUT, RIGHT-HAND THREAD.
AN316-7L = 7/16-20 STEEL NUT, LEFT-HAND THREAD.
AN316C7L = 7/16-20 CORROSION-RESISTANT STEEL, LEFT-HAND THREAD.

3. DIMENSIONS SHOWN ARE IN INCHES.

Figure 199. AN316 plain checknuts.

provided the cotterpin holes are free from burrs. Burs tend to tear the nonmetallic insert, rendering it unsatisfactory as a locking device. Bolts, studs, and screws of 1/4-inch diameter and under, with cotterpin holes, may be used with nonmetallic-insert, self-locking nuts only in an emer-



PART NUMBERS		SIZE AND THREAD
STEEL	BRASS	
AN350-632	AN350B632	NO. 6-32 NC-2B
AN350-832	AN350B832	NO. 8-32 NC-2B
AN350-1032	AN350B1032	NO. 10-32 NF-2B
AN350-4	AN350B4	1/4-28 UNF-2B
AN350-5	AN350B5	5/16-24 UNF-2B
AN350-6	AN350B6	3/8-24 UNF-2B
AN350-7	AN350B7	7/16-20 UNF-2B
AN350-8	AN350B8	1/2-20 UNF-2B

NOTES:

1. EXAMPLES OF PART NUMBERS:

AN350-4 = 1/4-28 STEEL NUT.
AN350B4 = 1/4-28 BRASS NUT.

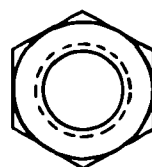
2. DIMENSIONS SHOWN ARE IN INCHES.

Figure 200. AN350 wingnuts.

gency. These nuts will be replaced as soon as possible with the specified type. Before reusing a nonmetallic-insert, self-locking nut of 1/2-inch diameter and smaller, test for minimum prevailing torque by attempting to insert a matching screw or bolt by hand. Reuse only those nuts that cannot be tightened with fingers after insert engages bolt or stud. Test nuts over 1/2-inch in diameter for minimum prevailing torque, using values specified in table 42. Do not subject nonmetallic-insert, self-locking nuts to temperatures in excess of 250°F. (121°C.).

Caution: Self-locking nuts will not be reused in critical applications, refer to TM 55-1500-204-25/1.

(2) *Plate nuts.* Plate nuts, also called anchor nuts, are shown in figures 203 through 205. These self-locking nuts, AN256, AN362, AN366, NAS1027, and NAS1030, are used to give flexibility in locations where the self-locking feature is required for use. These nuts must be handled and installed carefully to prevent them from being deformed. Bases are countersunk for flush mounting, plain for modified welding, and equipped with nibs for projection welding (fig. 204). The floating anchor nut (fig. 205) is designed so the plate will hold the nut, with a sideways floating feature, approximately centered over a bolt or screw hole. When the bolt is properly tightened, the nut rests firmly against its holder. Floating anchor nuts are for structural usage and should be used in locations where the temperature does not exceed 250°F. (121°C.).



STEEL		BRASS	ALUMINUM ALLOY	SIZE AND THREAD
FINE THREAD				
MS20364-1032	MS20364B1032	MS20364D1032		NO. 10-32
MS20364-428	MS20364B428	MS20364D428		1/4-28
MS20364-524	MS20364B524	MS20364D524		5/16-24
MS20364-624	MS20364B624	MS20364D624		3/8-24
MS20364-720	MS20364B720	MS20364D720		7/16-20
MS20364-820	MS20364B820	MS20364D820		1/2-20
MS20364-918	MS20364B918	MS20364D918		9/16-18
MS20364-1018	MS20364B1018	MS20364D1018		5/8-18
MS20364-1216	MS20364B1216	MS20364D1216		3/4-16
MS20364-1414	MS20364B1414	MS20364B1414		7/8-14
MS20364-1614	MS20364B1614	MS20364D1614		1-14
MS20364-1812	MS20364B1812	MS20364D1812		1-1/8-12
MS20364-2012	MS20364B2012	MS20364D2012		1-1/4-12
COARSE THREAD				
MS20364-632		MS20364D632		NO. 6-32
MS20364-832		MS20364D832		NO. 8-32

NOTES:

1. ADD A AFTER DASH NUMBER FOR NUTS HAVING NONMETALLIC INSERTS.
2. ADD C AFTER DASH NUMBER FOR NUTS FABRICATED ENTIRELY FROM METAL.
3. EXAMPLES OF PART NUMBERS:

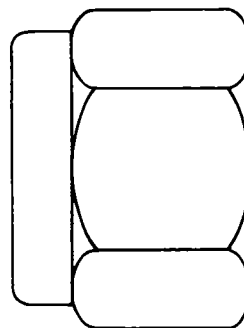
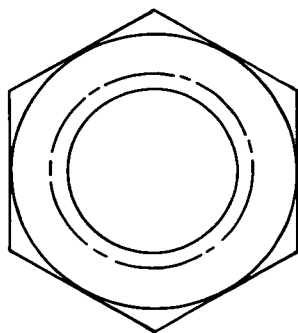
MS20364-428 - 1/4-28 STEEL NUT, EITHER ALL METAL OR WITH NONMETALLIC INSERT.
MS20364D428 - 1/4-28 ALUMINUM ALLOY NUT, EITHER ALL METAL OR WITH NONMETALLIC INSERT.
MS20364B428A - 1/4-28 COPPER BASE ALLOY NUT WITH NONMETALLIC INSERT.
MS20364-428C - 1/4-28 STEEL NUT, ALL METAL.

4. DIMENSIONS SHOWN ARE IN INCHES.

Figure 201. MS20364 self-locking nuts.

(3) *Engine self-locking nuts.* Engine self-locking nuts are used when specified by the manufacturer on assembly drawings, parts lists, bills of material, or in the applicable illustrated parts breakdown manual for a particular type or model of engine or accessory. Do not use No. 10 or 1/4-inch size self-locking nuts with drilled studs. The new type engine self-locking nut is shown in figure 206.

(4) *Internal wrenching nuts.* Internal wrenching nuts, NAS443, are used where heat-treated, self-locking nuts are specified to carry high-strength bolt tension loads.



STEEL		BRASS	ALUMINUM ALLOY
FINE THREAD			SIZE AND THREAD
MS20365-1032	MS20365B1032	MS20365D1032	NO. 10-32
MS20365-428	MS20365B428	MS20365D428	1/4-28
MS20365-524	MS20365B524	MS20365D524	5/16-24
MS20365-624	MS20365B624	MS20365D624	3/8-24
MS20365-720	MS20365B720	MS20365D720	7/16-20
MS20365-820	MS20365B820	MS20365D820	1/2-20
MS20365-918	MS20365B918	MS20365D918	9/16-18
MS20365-1018	MS20365B1018	MS20365D1018	5/8-18
MS20365-1216	MS20365B1216	MS20365D1216	3/4-16
MS20365-1414	MS20365B1414	MS20365D1414	7/8-14
MS20365-1614	MS20365B1614	MS20365D1614	1-14
MS20365-1812	MS20365B1812	MS20365D1812	1-1/8-12
MS20365-2012	MS20365B2012	MS20365D2012	1-1/4-12
COARSE THREAD			SIZE AND THREAD
MS20365-440	MS20365B440	MS20365D440	NO. 4-40
MS20365-632	MS20365B632	MS20365D632	NO. 6-32
MS20365-832	MS20365B832	MS20365D832	NO. 8-32

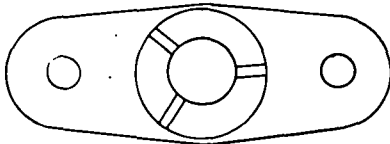
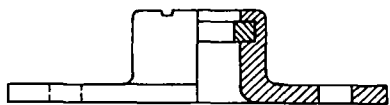
NOTES:

1. ADD A AFTER DASH NUMBER FOR NUTS HAVING NONMETALLIC INSERTS.
2. ADD C AFTER DASH NUMBER FOR NUTS FABRICATED ENTIRELY FROM METAL.
3. EXAMPLES OF PART NUMBERS:
 - MS20365-428 = 1/4-28 STEEL NUT, EITHER ALL METAL OR WITH NONMETALLIC INSERT.
 - MS20365D428 = 1/4-28 ALUMINUM ALLOY NUT, EITHER ALL METAL OR WITH NONMETALLIC INSERT.
 - MS20365B428A = 1/4-28 COPPER BASE ALLOY NUT WITH NONMETALLIC INSERT.
 - MS20365-428C = 1/4-28 STEEL NUT, ALL METAL.
4. DIMENSIONS SHOWN ARE IN INCHES.

Figure 202. MS20365 self-locking nuts.

(5) *Sheet spring nuts.* Sheet spring nuts (fig. 207), NAS444 through NAS446 and NAS395, commonly known as speed nuts, are used in conjunction with standard and sheet metal self-tapping screws in various nonstructural locations. Speed nuts are used in supporting line clamps, conduit clamps, electrical equipment, access doors, and other similar items.

Speed nuts are made from spring steel and are arched prior to tightening. The arched spring lock prevents the screw from working loose. They are easily inserted, and finger pressure keeps them from turning. The use of wrenches is unnecessary. Use speed nuts only where originally used in fabrication of the aircraft.



PART NUMBERS		SIZE AND THREAD
STEEL	ALUMINUM ALLOY	
FINE THREAD		
AN366F1032	AN366DF1032	NO. 10-32
AN366F428	AN366DF428	1/4-28
AN366F524	AN366DF524	5/16-24
AN366F624	AN366DF624	3/8-24
COARSE THREAD		
AN366F632	AN366DF632	NO. 6-32
AN366F832	AN366DF832	NO. 8-32

NOTES:

1. ADD A AFTER DASH NUMBER FOR SELF-LOCKING PLATE NUTS HAVING NONMETALLIC INSERTS.
2. ADD B AFTER DASH NUMBER FOR SELF-LOCKING PLATE NUTS FABRICATED ENTIRELY OF METAL.
3. EXAMPLES OF PART NUMBERS:
 - AN366F428 = 1/4-28 SELF-LOCKING STEEL PLATE NUT, EITHER ALL METAL OR WITH NONMETALLIC INSERT.
 - AN366DF428 = 1/4-28 SELF-LOCKING ALUMINUM ALLOY PLATE NUT, EITHER ALL METAL OR WITH NONMETALLIC INSERT.
 - AN366DF428A = 1/4-28 SELF-LOCKING ALUMINUM ALLOY PLATE NUT WITH NON-METALLIC INSERT.
 - AN366F428B = 1/4-28 SELF-LOCKING STEEL, ALL METAL, PLATE NUT.
4. DIMENSIONS SHOWN ARE IN INCHES.

Figure 203. AN366 plate nut.

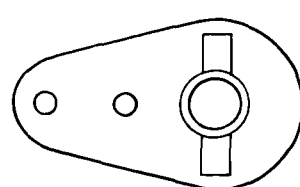
Table 42. Minimum Prevailing Torque Values for Used Self-locking Nuts of Over 1/2-Inch Diameter

Nut size	Minimum prevailing torque* (inch-pounds)
Fine thread	
5/16-18	13
3/8-18	18
3/4-16	27
7/8-14	40
1-14	55
1 1/8-12	73
1 1/4-12	94
Coarse thread	
5/16-12	14
3/8-11	18
3/4-10	27
7/8-9	38
1-8	51
1 1/8-8	68
1 1/4-8	88

* Reading established when bolt or stud fully engages insert.



BOOTS WING STYLE
CORNER ANCHOR NUT



BOOTS WING STYLE
ONE-LUG, TWO-RIVET
ANCHOR NUT



BOOTS WING STYLE
ANCHOR NUT WITH
COUNTERSUNK RIVET HOLES



BOOTS WING STYLE
ANCHOR NUT WITH
WELDING NIBS

Figure 204. Plate nut styles.

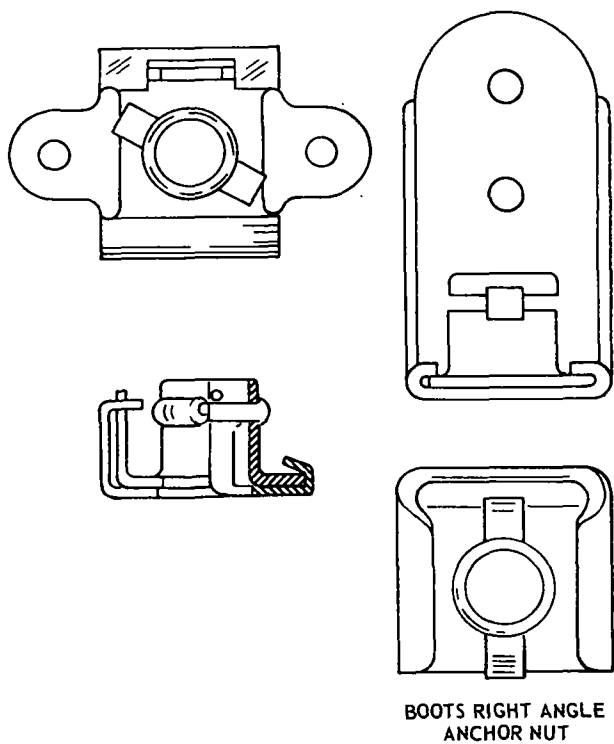


Figure 205. Floating anchor nuts.

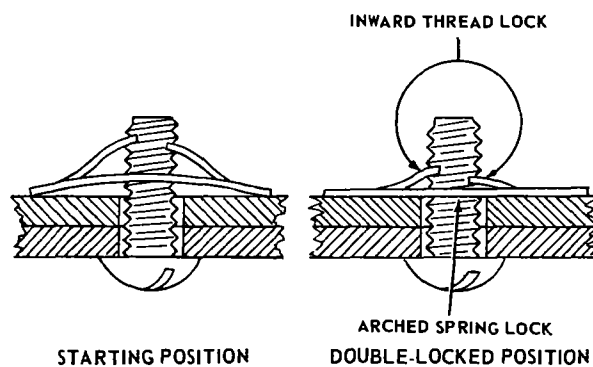


Figure 207. Sheet spring nut.

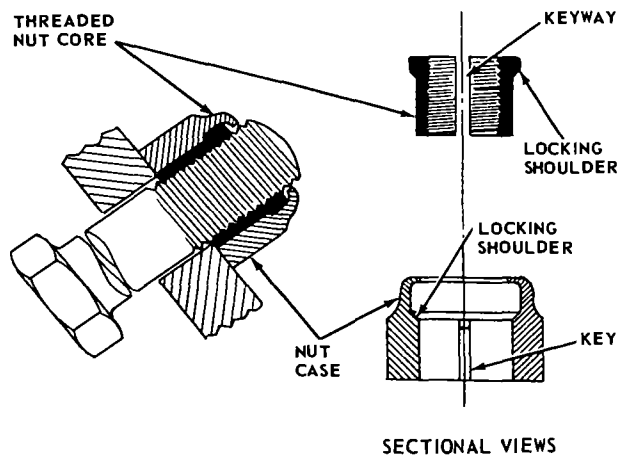
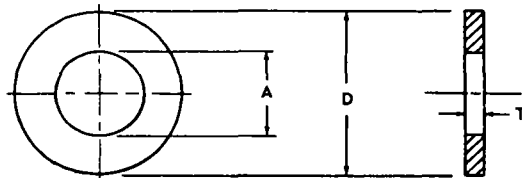


Figure 206. Engine self-locking nut.



BOLT SIZE	A DIA	D + 0.020 - 0.005 DIA	T	DASH NUMBERS				
				CARBON STEEL	CORROSION- RESISTANT STEEL	ALUMINUM ALLOY		BRASS
						TREATED SURFACES	UNTREATED SURFACES	
NO. 3	0.105	0.250	0.016 0.032	3L 3	C3L C3	PD3L PD3	D3L D3	B3
NO. 4	0.125	0.312	0.016 0.032 0.035	4L 4	C4L C4	PD4L PD4	D4L D4	B4
NO. 5	0.140	0.438	0.042					
NO. 6	0.149	0.375	0.016 0.032	6L 6	C6L C6	PD6L PD6	D6L D6	B6
NO. 8	0.174	0.375	0.016 0.032	8L 8	C8L C8	PD8L PD8	D8L D8	B8
NO. 10	0.203	0.438	0.016 0.032 0.049 0.063	10L	C10L	PD10L	D10L	B10
				10	C10	PD10	D10	
1/4	0.265	0.500	0.016 0.032 0.063	416L 416	C416L C416	PD416L PD416	D416L D416	B416
5/16	0.328	0.562	0.016 0.032 0.063	516L 516	C516L C516	PD516L PD516	D516L D516	B516
3/8	0.390	0.625	0.016 0.032 0.063	616L 616	C616L C616	PD616L PD616	D616L D616	B616
7/16	0.453	0.750	0.016 0.032 0.063	716L 716	C716L C716	PD716L PD716	D716L D716	B716
1/2	0.515	0.875	0.016 0.032 0.063	816L 816	C816L C816	PD816L PD816	D816L D816	B816
9/16	0.578	1.062	0.016 0.032 0.063	916L 916	C916L C916	PD916L PD916	D916L D916	B916
5/8	0.640	1.188	0.016 0.032 0.063	1016L 1016	C1016L C1016	PD1016L PD1016	D1016L D1016	B1016
3/4	0.765	1.312	0.016 0.032 0.090	1216L 1216	C1216L C1216	PD1216L PD1216	D1216L D1216	B1216
7/8	0.890	1.500	0.016 0.032 0.090	1416L 1416	C1416L C1416	PD1416L PD1416	D1416L D1416	B1416
1	1.015	1.750	0.016 0.032 0.090	1616L 1616	C1616L C1616	PD1616L PD1616	D1616L D1616	B1616
1-1/16	1.078	1.812	0.016 0.032 0.090	1716L 1716	C1716	PD1716L PD1716	D1716L D1716	B1716
1-1/8	1.140	1.875	0.016 0.032 0.090	1816L 1816	C1816	PD1816L PD1816	D1816L D1816	B1816

Figure 208. AN960 plain washers.

BOLT SIZE	A DIA	D +0.020 -0.005 DIA	T	DASH NUMBERS				
				CARBON STEEL	CORROSION- RESISTANT STEEL	ALUMINUM ALLOY		BRASS
						TREATED SURFACES	UNTREATED SURFACES	
1-1/4	1.265	2.000	0.016 0.032 0.090	2016L 2016	C2016	PD2016L PD2016	D2016L D2016	B2016
1-5/16	1.328	2.062	0.016 0.032 0.090	2116L 2116	C2116	PD2116L PD2116	D2116L D2116	B2116
1-5/8	1.640	2.375	0.016 0.032 0.090	2616L 2616	C2616	PD2616L PD2616	D2616L D2616	B2616
1-7/8	1.890	2.625	0.016 0.032 0.090	3016L 3016	C3016	PD3016L PD3016L	D3016L D3016	B3016
2-1/4	2.265	3.000	0.016 0.032 0.090	3616L 3616	C3616	PD3616L PD3616	D3616L D3616	B3616
2-1/2	2.515	3.250	0.016 0.032 0.090	4016L 4016	C4016	PD4016L PD4016	D4016L D4016	B4016

NOTES:

1. P CODING IN TABLE IDENTIFIES ALUMINUM ALLOY WASHERS WITH TREATED SURFACES.

2. L CODING IN TABLE IDENTIFIES THE LIGHT SERIES OF WASHERS.

3. EXAMPLES OF PART NUMBERS:

AN960-716 = CARBON STEEL WASHER FOR 7/16-INCH BOLT SIZE, 0.064 INCH THICK.

AN960PD10L = ALUMINUM ALLOY WASHER FOR NO. 10 BOLT SIZE, 0.016 INCH THICK, WITH TREATED SURFACES.

4. MATERIALS: CARBON STEEL, CORROSION-RESISTANT STEEL, ALUMINUM ALLOY, AND BRASS.

5. DIMENSIONS SHOWN ARE IN INCHES.

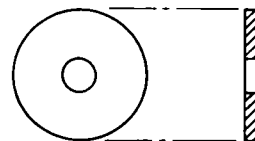
Figure 208—Continued

Section IV. AIRCRAFT WASHERS

119. Types and Applications

a. Plain Washers. Plain washers, AN960 (fig. 208), are used under AN hexagon nuts to provide a smooth bearing surface, to act as a shim in obtaining the correct relationship between threads of the bolt and nut, and to adjust the position of castellated nuts with respect to drilled cotterpin holes in bolts. Use a cadmium-plated steel washer under the nut, with the washer bearing directly against the structure, unless otherwise specified. Use aluminum alloy plain washers under boltheads or nuts on aluminum alloy or magnesium structures where corrosion is a factor. Use plain washers, MS63040 (fig. 209), in wooden structures under boltheads and nuts to prevent local crushing of surface. Brass nonstructural washers, AN961, are used in electrical components and instrument mounting where nonmagnetic properties are required. Plain washers should always be used under lockwashers to prevent damage to material surface.

b. Lockwashers. Lockwashers, AN935 (split type) (fig. 210), and AN936 (internal-, external-, or countersunk-teeth types) (fig. 211), are used with plain nuts when self-locking or castellated-type nuts are not applicable. Spring action of the washer provides enough friction to prevent loosening of the nut from vibration.



DASH NUMBERS	BOLT SIZE
-3	NO. 10
-4	1/4
-5	5/16
-6	3/8
-7	7/16
-8	1/2
-9	9/16
-10	5/8

NOTES:

1. EXAMPLE OF PART NUMBER:

MS63040-4 - 1/4-INCH BOLT SIZE

2. MATERIAL: STEEL

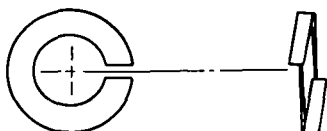
3. DIMENSIONS SHOWN ARE IN INCHES

Figure 209. MS63040 plain washers.

Lockwashers should never be used under any of the following conditions:

(1) As fastenings to primary or secondary structures.

(2) As fastenings on any part of the air-



DASH NUMBERS		BOLT SIZE
REGULAR	LIGHT	
2	2L	NO. 2 (0.086)
3	3L	NO. 3 (0.099)
4	4L	NO. 4 (0.112)
5	5L	NO. 5 (0.125)
6	6L	NO. 6 (0.138)
8	8L	NO. 8 (0.164)
10	10L	NO. 10 (0.190)
12	12L	NO. 12 (0.216)
416	416L	1/4
516	516L	5/16
616	616L	3/8
716	716L	7/16
816	816L	1/2
916	916L	9/16
1016	1016L	5/8
1216	1216L	3/4

NOTES:

1. EXAMPLES OF PART NUMBERS:

AN935-10 - WASHER FOR NO. 10 BOLT,
REGULAR.

AN935-10L - WASHER FOR NO. 10 BOLT,
LIGHT.

2. MATERIAL: STEEL.

3. DIMENSIONS SHOWN ARE IN INCHES.

Figure 210. AN935 lockwashers.

craft where failure might result in damage or danger to the aircraft or personnel.

(3) Where failure would permit the opening of a joint to the airflow.

(4) Where the washers are exposed to the airflow.

(5) Where the screw is subject to frequent removal.

(6) Where the washers are subject to corrosive conditions.

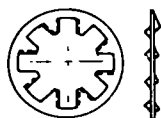
(7) Where the washer is against soft material without a plain washer underneath to prevent gouging the surface.

120. Special Washers

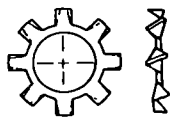
a. Taper Pin Washers. Taper pin (dished) washers, AN975 (fig. 212), are used in conjunction with threaded taper pins, AN386. Install washer under nut, AN320, to effect adjustment where a plain washer would cause distortion.

b. High Tensile Washers. High tensile washers, MS20002 (fig. 213), are used in conjunction with high tensile internal wrenching bolts, MS20004 through MS20024. Type C washer is countersunk to seat the bolthead shank radius, and a plain type washer is used under the nut. Plain and countersunk high tensile washers, MS20002 and MS20002C, are heat-treated to 125,000 to 145,000 psi. These washers are identified in figure 213.

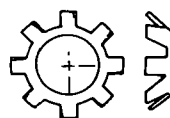
c. Countersunk Washers. Countersunk washers, commonly called dimpled washers, are for use with 100-degree, flathead screws or rivets to provide reinforced, low-profile attachments in such locations as fillets and other fairing installations.



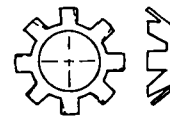
TYPE A
INTERNAL TEETH



TYPE B
EXTERNAL TEETH



TYPE C 82-DEGREE
COUNTERSUNK TEETH



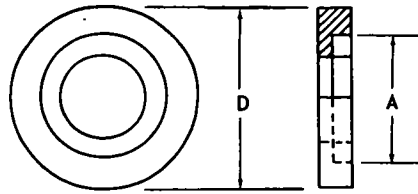
TYPE D 100-DEGREE
COUNTERSUNK TEETH

INTERNAL TEETH			EXTERNAL TEETH			COUNTERSUNK TEETH			COUNTERSUNK TEETH		
BOLT SIZE	DASH NUMBER		DASH NUMBER			DASH NUMBER			DASH NUMBER		
	STEEL	BRONZE	STEEL	BRONZE		STEEL	BRONZE		STEEL	BRONZE	
NO. 2	A2	-	-	-		C2	C2B		D2	-	
NO. 3	A3	-	B3	B3B		-	-		-	-	
NO. 4	A4	A4B	B4	B4B		C4	C4B		D4	-	
NO. 6	A6	A6B	B6	B6B		C6	C6B		D6	-	
NO. 8	A8	A8B	B8	B8B		C8	C8B		D8	-	
NO. 10	A10	A10B	B10	B10B		C10	C10B		D10	-	
1/4	A416	A16B	B416	B416B		C416	C416B		-	-	
1/4	A416H	-	-	-		-	-		-	-	
5/16	A516	A516B	B516	B516B		C516	C516B		-	-	
3/8	A616	A616B	B616	B616B		C616	C616B		-	-	
7/16	A716	A716B	B716	B716B		C716	C716B		-	-	
7/16	(SEE NOTE 1.)		-	-		-	-		-	-	
7/16	A716S	A716BS	-	-		-	-		-	-	
1/2	A816	-	B816	-		-	-		-	-	
9/16	A916	-	B916	-		-	-		-	-	
5/8	A1016	-	B1016	-		-	-		-	-	
3/4	A1216	-	B1216	-		-	-		-	-	
7/8	A1416	-	B1416	-		-	-		-	-	
1	A1616	-	B1616	-		-	-		-	-	

NOTES:

1. THIS WASHER HAS ALTERNATE TEETH TWISTED IN A DIRECTION OPPOSITE TO THAT OF THE OTHER TEETH.
2. EXAMPLE OF PART NUMBER:
AN936B416B - WASHER, EXTERNAL TEETH, FOR 1/4-INCH BOLT, BRONZE.
3. MATERIAL: STEEL, BRONZE
4. DIMENSIONS SHOWN ARE IN INCHES.

Figure 211. AN936 lockwashers.

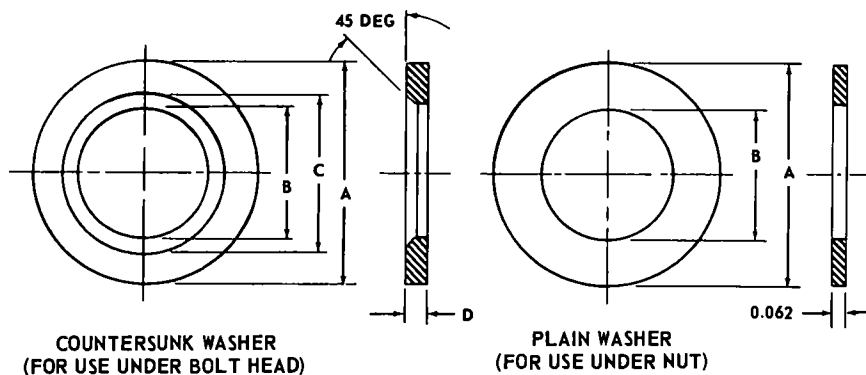


AN NUMBER	BOLT SIZE	D	A
AN975-3	NO. 10	15/16	11/32
AN975-4	1/4	9/16	13/32
AN975-5	5/16	11/16	17/32
AN975-6	3/8	25/32	19/32
AN975-7	7/16	27/32	21/32
AN975-8	1/2	15/16	23/32
AN975-9	9/16	1-3/32	27/32
AN975-12	3/4	1-9/32	1
AN975-14	7/8	1-15/32	1-3/16

NOTE5:

1. MATERIAL: STEEL.
2. DIMENSIONS SHOWN ARE IN INCHES.

Figure 212. AN975 taper pin washers.



COUNTERSUNK WASHER
(FOR USE UNDER BOLT HEAD)

PLAIN WASHER
(FOR USE UNDER NUT)

BOLT SIZE	MS PART NUMBER		A DIA	B DIA		C DIA		D	FLATNESS TOLERANCE
	COUNTERSUNK	PLAIN		MAX	MIN	MAX	MIN		MAX
1/4 5/16 3/8	M520002C4 M520002C5 M520002C6	M520002-4 M520002-5 M520002-6	0.531 0.593 0.687	0.260 0.324 0.388	0.252 0.315 0.378	0.344 0.406 0.495	0.334 0.396 0.483	0.078	0.007
7/16 1/2 9/16	M520002C7 M520002C8 M520002C9	M520002-7 M520002-8 M520002-9	0.781 0.875 0.968	0.451 0.515 0.579	0.441 0.504 0.568	0.557 0.620 0.687	0.543 0.604 0.667	0.078	0.007 0.007 0.010
5/8 3/4 7/8	M520002C10 M520002C12 M520002C14	M520002-10 M520002-12 M520002-14	1.062 1.250 1.437	0.643 0.770 0.897	0.631 0.757 0.884	0.785 0.910 1.035	0.765 0.890 1.015	0.078	0.010
1 1-1/8 1-1/4	M520002C16 M520002C18 M520002C20	M520002-16 M520002-18 M520002-20	1.625 1.875 2.125	1.025 1.150 1.275	1.010 1.135 1.260	1.160 1.285 1.447	1.140 1.265 1.427	0.078 0.078 0.094	0.010
1-3/8 1-1/2	M520002C22 M520002C24	M520002-22 M520002-24	2.313 2.500	1.400 1.525	1.385 1.510	1.572 1.697	1.552 1.677	0.094	0.015

NOTE5:

1. MATERIAL: STEEL.
2. DIMENSIONS SHOWN ARE IN INCHES.

Figure 213. MS20002 high tensile washers.

Section V. INSTALLATION OF BOLTS AND NUTS

121. Bolt and Bolthole Sizes

a. Slight clearances in boltholes are permissible when bolts are used in tension and are not subject to reversal of load. A few of the applications in which clearance of holes may be permitted are in pulley brackets, conduit boxes, lining trim, and miscellaneous supports and brackets. Light-drive fits for bolts (specified on the repair drawings as 0.0015-inch maximum clearance between bolt and hole) are required in places where they are placed in the original structure.

b. The fit of holes and bolts cannot be defined in terms of shaft and hole diameters; it is defined in terms of friction between bolt and hole when sliding bolt in place. A tight-drive fit, for example, is one in which a sharp blow of a 12- or 14-ounce hammer is required to move the bolt. A bolt that requires a hard blow and sounds tight is considered to fit too tightly. A light-drive fit is one in which a bolt will move when a hammer handle is held against the bolt-head and pressed by body weight. A bolt which moves when pushed with the thumb is considered too loose.

c. To obtain a light-drive fit, measure several bolts of the correct nominal size with a micrometer; then separate them into three groups—large, medium, and small. The nominal size is the quoted size, not the actual size. Drill an initial hole approximately 1/32 inch undersize (1/8 inch undersize may be used for larger bolts) and then drill to 1/64 inch undersize.

d. Select a reamer which can cut a hole that will give proper drag when using the smallest bolts. Ream two or three holes and fit the small bolts in the reamed holes. If the hole is too small, make it larger by selecting another reamer of the same nominal size, but which will cut a hole slightly larger. If any of these holes are too large for light-drive fit conditions with the small bolts, then the medium or large bolts will probably be just right for a light-drive fit. Refer to table 43 for drill sizes when drilling holes for AN bolts.

e. Boltholes must not be oversize or elongated. A bolt in such a hole will carry none of its shear load until parts have yielded or deformed enough to allow the bearing surface of the oversized hole to come in contact with the bolt. In this respect, remember that bolts do not become swaged to fill up the hole as do rivets. Therefore for oversized or elongated holes, it is permissible to drill or ream the hole to accom-

modate the next larger bolt, provided the larger hole size does not weaken the part.

Table 43. AN Bolt Drill Sizes

Bolt diameter	Pilot hole drill size	Final drill or ream size
3/16 (10-32)	No. 21 (0.159)	No. 11 (0.191)
1/4	7/32 (0.2187)	1/4 (0.250)
5/16	9/32 (0.2812)	5/16 (0.3125)
3/8	11/32 (0.3437)	3/8 (0.375)
7/16	13/32 (0.4062)	7/16 (0.4375)
1/2	15/32 (0.4687)	1/2 (0.500)
5/8	17/32 (0.531)	5/8 (0.625)
3/4	19/32 (0.594)	3/4 (0.750)
7/8	23/32 (0.719)	7/8 (0.875)
1	27/32 (0.844)	1 (1.000)
	31/32 (0.969)	

122. Use and Application of Torque

a. To avoid stripping threads, cracking nuts, or snapping bolts, and to assure that all bolts carry their share of the load, all nuts should be torqued. This means that for every nut installed, the tightening or twisting force should be measured or, after much experience, estimated accurately so the twisting force will be correct.

b. Torque is the product of applied force and the distance it is applied from center of the nut. This value may be expressed in inch-pounds or foot-pounds; the force is measured in pounds, and the distance from center of the nut is measured in inches or feet. Thus, a force of 40 pounds applied at the end of a wrench 12 inches long will develop a twisting force of 480 inch-pounds. If 40 pounds of force were applied at the end of a 3-foot bar and wrench, a twisting force of 120 foot-pounds would be developed. This value could also be given as 1440 inch-pounds.

c. Nuts which are tightened without a torque wrench are seldom drawn up to the correct tightness. They are either overtightened because of the variable involved, or they are undertightened because of unsuspected friction. Such guesswork may result in aircraft failure. Tables showing torque values of bolts have not been set up for aircraft use, but torque tables to be used when tightening nuts have been established. Use these torque tables when installing nuts. Follow the instructions in the manual for the specific aircraft.

Note. Table 44 lists the recommended torque values for a few nuts which are used in aircraft repairs.

d. When applying torque to a nut, always use proper tools to prevent damaging the nut. Socket and box-end wrenches are preferred to open-end

wrenches, as they will not damage the corners of the nut.

Caution: These torque values are derived from oil-free cadmium plated threads.

Table 44. Recommended Torque Value

Fine thread				
Size and thread	MS20365 and AN310 castellated nuts	MS20364 and AN320 castle shear nuts	90,000 PSI bolts, MS20365 and AN310 castellated nuts	90,000 PSI bolts, MS20364 and AN320 castle shear nuts
No. 8-36	12-15	7-9	20	12
No. 10-32	20-25	12-15	40	25
1/4-28	50-70	30-40	100	60
5/16-24	100-140	60-85	225	140
3/8-24	160-190	95-110	390	240
7/16-20	450-500	270-300	840	500
1/2-20	480-690	290-410	1100	660
5/8-18	800-1000	480-600	1600	960
3/4-18	1100-1300	600-780	2400	1400
1-16	2300-2500	1300-1500	5000	3000
1-14	2500-3000	1500-1800	7000	4200
1-14	3700-5500	2200-3300	10000	6000
		(see note 2.)		
1 1/8-12	5000-7000	3000-4200	15000	9000
		(see note 2.)		
1 1/4-12	9000-1100	5400-6000	25000	15000
		(see note 2.)		
Coarse thread				
No. 8-32	12-15	7-9	20	12
No. 10-24	20-25	12-15	35	21
1/4-20	40-50	25-30	75	45
5/16-18	80-90	48-55	160	100
3/8-16	160-185	95-100	275	170
7/16-14	235-255	140-155	475	280
1/2-13	400-480	240-290	880	520
5/8-12	500-700	300-420	1100	650
3/4-11	700-900	420-540	1500	900
1-10	1150-1600	700-950	2500	1500
1 1/8-9	2200-3000	1300-1800	4600	2700

Note 1. The above torque loads may be used for all cadmium plated steel nuts of the fine or coarse thread series which have approximately equal number of threads and equal face bearing areas.

Note 2. Estimated corresponding values.

Note 3. Torque values are in inch-pounds.

Section VI. AIRCRAFT SCREWS

123. Description and Classification

a. *Description.* Screws are the most commonly used threaded fastening devices on aircraft. They differ from bolts in that they are generally made of lower strength materials. Some screws have no clearly defined grip or unthreaded portion, while others are threaded along their entire length. They can be installed with a loose-fitting thread, and the head shapes are made to engage a screwdriver or wrench. The Phillips or Frearson recessed head is optional on several

types of screws. For proper performance, use a Phillips screwdriver with Phillips head screws and a Frearson screwdriver with Frearson head screws.

b. *Classification.* Screws may be classified in three groups: structural screws, which have the same strength as equal size bolts; machine screws, which include the majority of types used for general repair; and self-tapping screws, which are used for attaching lighter parts.

124. Identification and Coding

The coding system used to identify screws is similar to that used for bolts. There are AN, NAS, and MS screws. Part numbers such as 510, 515, and 550 catalog screws into classes such as roundhead, flathead, and washer head. Letters and digits indicate the material composition, length, and thickness. The following are examples of screw code numbers:

a. AN500-6-7.

AN = Army-Navy standard
500 = fillister-head, coarse thread
6 = diameter size—number 6
7 = length in sixteenths of an inch

Note. When a material code letter does not follow the part number, the material is alloy steel.

b. AN501B-416-7.

AN = Army-Navy standard
501 = fillister-head, fine thread
B = brass
416 = $\frac{1}{16}$ -inch diameter
7 = $\frac{7}{16}$ inch long

Note. The letter D in place of B would indicate material to be 2017T aluminum alloy. The letter C would designate corrosion-resistant steel. An A placed before material code would indicate that the head is drilled for safetying.

c. NAS228DD-8.

NAS = National Aircraft Standard
228 = brazier-head recessed for a Frearson screw-driver
DD = 2024T aluminum alloy
8 = length in sixteenths of an inch

d. MS24620D-8.

MS = Military Standard
24620 = flat recessed head
D = 2017T aluminum alloy
8 = length in sixteenths of an inch

Note. For markings used on screw heads to identify physical characteristics and contents of screws, refer to figure 186.

125. Types of Screws

a. *Structural Screws.* Structural screws are made of alloy steel, are properly heat-treated, and can also be used as structural bolts. These screws are found in the NAS220 through NAS-235 (fig. 214), AN509 (fig. 215), and AN525 (fig. 216) series. They have definite grips and the same shear strength as bolts of the same size. Shank tolerances are similar to AN hexagon head bolts, and the threads are National Fine. Structural screws are available with round, brazier, or countersunk heads. The recessed head screws are driven by either a Phillips or Frearson screwdriver.

(1) The AN509 (100-degree) flathead screw is used in countersunk holes where a flush surface is necessary.

(2) The AN525 washer head screw and the NAS220 through NAS235 roundhead screws are used where raised heads are not objectional. The

washer head screw provides a larger contact area.

b. *Machine Screws.* Machine screws are usually of the flathead (countersunk), roundhead, or washer head types. These screws are general purpose screws and are available in low carbon steel, brass, corrosion-resistant steel, and aluminum alloy.

(1) Roundhead screws, AN515 and AN520 (fig. 217), are general purpose screws available in low carbon steel, brass, and corrosion-resistant steel and slotted or recessed heads. The AN515 screw has coarse threads and the AN520 has fine threads.

(2) Countersunk machine screws are listed as AN505 and AN510 (fig. 217) for 82 degrees, and AN507 for 100 degrees. The AN505 and AN510 countersunk machine screws correspond to the AN515 and AN520 roundhead machine screws in material and usage. The AN507 countersunk machine screw is a low carbon steel screw.

(3) Fillister head screws, AN500 through AN503 (fig. 218), are general purpose screws and are used as capscrews in light mechanisms. This could include attachments of cast aluminum parts such as gearbox cover plates.

(a) AN500 and AN501 fillister head screws (fig. 218) are available in low carbon steel, corrosion-resistant steel, and brass. The AN500 has coarse threads while the AN501 has fine threads. They have no clearly defined grip length. The screws that are larger than No. 6 have a hole drilled through the head for safetying purposes.

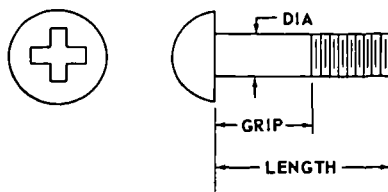
(b) AN502 fine-thread and AN503 coarse-thread, fillister head screws (fig. 218) are made of heat-treated alloy steel and have a small grip. These screws are used as capscrews where great strength is required. The AN503 coarse-thread screws are commonly used as capscrews in tapped aluminum alloy and magnesium castings because of the softness of the metal.

c. *Self-Tapping Screws.* Self-tapping screws include machine, sheet metal, and drive screws. These screws cut their own threads after the part has been underdrilled.

Caution: Never use self-tapping screws to replace standard bolts, nuts, screws, or rivets in the original structure.

(1) AN504 machine self-tapping screws (fig. 219) are used to attach removable parts such as nameplates and other similar items to castings. The AN504 screw has a round head. Hole sizes and sheet data are given in table 45.

(2) MS24619 through MS24622 and MS-24639 through MS24642 self-tapping sheet metal



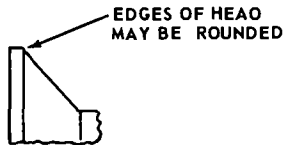
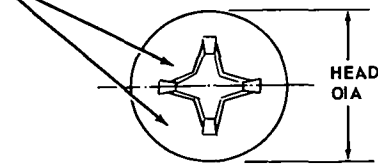
BRAZIER HEAD NAS NUMBERS	PHILLIPS	220	221	222	223	224	225	226	227
	FREARSON	228	229	230	231	232	233	234	235
SIZE AND THREAD		NO. 8-32	NO. 10-32	1/4-28	5/16-24	3/8-24	7/16-20	1/2-20	9/16-18
DIAMETER		0.1640 0.1610	0.1890 0.1860	0.2490 0.2460	0.3115 0.3085	0.3740 0.3710	0.4365 0.4325	0.4990 0.4950	0.5615 0.5575
ALUMINUM ALLOY	TENSILE STRENGTH	480	710	1310	2080	3240	4350	5920	7550
	SHEAR STRENGTH	740	990	1715	2685	3870	5750	6850	8700
HIGH STRENGTH BRONZE	TENSILE STRENGTH	636	1014	1753	2815	4370	5890	8084	10230
	SHEAR STRENGTH	954	1280	2212	3463	4980	6780	8850	11190
ALLOY STEEL	TENSILE STRENGTH	1150	1690	3130	4980	7740	10430	14190	18100
	SHEAR STRENGTH	1540	2125	3680	5750	8280	11250	14700	18711
DASH NUMBER	LENGTH	GRIP	GRIP	GRIP	GRIP	GRIP	GRIP	GRIP	GRIP
7	7/16	1/32							
8	1/2	3/32	1/16						
9	9/16	5/32	1/8	1/16	1/32				
10	5/8	7/32	3/16	1/8	3/32				
11	11/16	9/32	1/4	3/16	5/32	3/32	1/16		
12	3/4	11/32	5/16	1/4	7/32	5/32	1/8		
13	13/16	13/32	3/8	5/16	9/32	7/32	3/16	1/16	
14	7/8	15/32	7/16	3/8	11/32	9/32	1/4	1/8	
15	15/16	17/32	1/2	7/16	13/32	11/32	5/16	3/16	
16	1	19/32	9/16	1/2	15/32	13/32	3/8	1/4	
17	1-1/16	21/32	5/8	9/16	17/32	15/32	7/16	5/16	
18	1-1/8	23/32	11/16	5/8	19/32	17/32	1/2	3/8	9/32
19	1-3/16	25/32	3/4	11/16	21/32	19/32	9/16	7/16	11/32
20	1-1/4	27/32	13/16	3/4	23/32	21/32	5/8	1/2	13/32

NOTES:

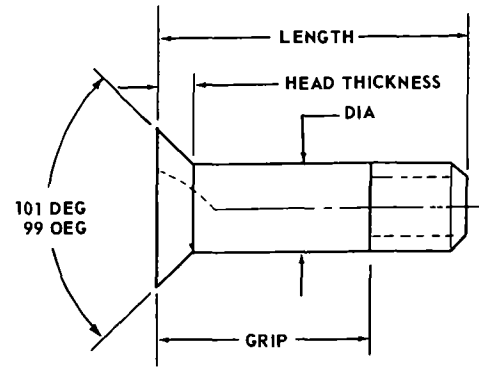
1. ADD DD TO BASIC PART NUMBER FOR ALUMINUM ALLOY.
2. ADD BZ TO BASIC PART NUMBER FOR HIGH STRENGTH BRONZE.
3. NO LETTER INDICATES ALLOY STEEL.
4. LENGTH TO BE SPECIFIED IN 1/16-INCH INCREMENTS UP TO 1-1/2 INCHES, 1/8-INCH INCREMENTS FROM 1-1/2 INCHES TO 3 INCHES AND 1/4-INCH INCREMENTS FOR LENGTHS OVER 3 INCHES. SCREWS LESS THAN 7/32-INCH WILL BE THREADED TO WITHIN $0.032 + 0.032$ INCH OF THE HEAD.
- 0.000
5. EXAMPLES OF PART NUMBERS:
NAS228DD-8 - SCREW, 1/2-INCH LONG, ALUMINUM ALLOY.
NAS228-8 - SCREW, 1/2-INCH LONG, ALLOY STEEL.
6. TENSILE STRENGTH: ALUMINUM ALLOY - ULTIMATE ALLOWABLE TENSILE STRESS (FM) = 62,000 PSI.
HIGH STRENGTH BRONZE - ULTIMATE ALLOWABLE TENSILE STRESS (FM) = 85,000 PSI.
ALLOY STEEL - ULTIMATE ALLOWABLE TENSILE STRESS (FM) = 125,000 to 145,000 PSI.
7. GRIP LENGTHS NOT ALLOWABLE IN COUNTERSUNK-HEAD TYPE.
8. STRENGTHS SHOWN ARE IN POUNDS
9. DIMENSIONS SHOWN ARE IN INCHES.

Figure 214. NAS220 through NAS235 roundhead screws.

MARK STEEL SCREWS WITH X. MARK
CORROSION-RESISTANT SCREWS WITH —.
MARK BRONZE SCREWS WITH =. ONLY
ONE X, —, OR = NEED BE VISIBLE.
POSITION OPTIONAL



ENLARGED VIEW OF HEAD DIAMETER



RECESSED HEAD SCREW

SIZE AND THREAD	DIAMETER		HEAD DIAMETER		HEAD THICKNESS
	MAX	MIN	MAX	MIN	
NO. 8-32UNC-3A	0.1640	0.1610	0.332	0.319	0.068
NO. 10-32UNF-3A	0.1890	0.1860	0.385	0.371	0.080
1/4-28UNF-3A	0.2490	0.2460	0.507	0.491	0.106
5/16-24UNF-3A	0.3115	0.3085	0.635	0.617	0.133
3/8-24UNF-3A	0.3740	0.3710	0.762	0.742	0.159
7/16-20UNF-3A	0.4365	0.4325	0.890	0.868	0.186
1/2-20UNF-3A	0.4990	0.4950	1.017	0.992	0.213
9/16-18UNF-3A	0.5615	0.5575	1.145	1.118	0.240

NOTES:

1. NO LETTER BEFORE FIRST DASH NUMBER INDICATES STEEL SCREWS
2. ADD C BEFORE FIRST DASH NUMBER FOR CORROSION-RESISTANT STEEL SCREWS.
3. ADD DD BEFORE FIRST DASH NUMBER FOR ALUMINUM ALLOY SCREWS.
4. ADD R BETWEEN FIRST AND SECOND DASH NUMBERS FOR RECESSED HEAD SCREWS.
5. EXAMPLES OF PART NUMBERS:
AN509.10R12 - NO. 10 RECESSED HEAD STEEL SCREW, 25/32-INCH LONG.
AN509C10R12 - NO. 10 RECESSED-HEAD CORROSION-RESISTANT STEEL SCREW, 25/32-INCH LONG.
AN509DD10R12 - NO. 10 RECESSED-HEAD ALUMINUM ALLOY SCREW, 25/32-INCH LONG.
6. MATERIAL: STEEL, CORROSION-RESISTANT STEEL, ALUMINUM ALLOY.
7. DIMENSIONS SHOWN ARE IN INCHES.

Figure 215. AN509 flathead screws.

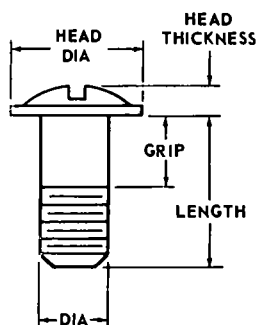
screws (fig. 219) are used in temporary attachment of sheet metal for riveting, and for permanent assembly on nonstructural assemblies where ability to insert screws in blind application is required (fig. 220). These screws are case-hardened for use on steel or aluminum alloy sheets. To install, drill a hole in accordance with table 46, and insert screw.

(3) Drive screws, AN535 (fig. 219), are plain head, self-tapping screws used as capscrews in the attachment of nameplates in castings or in sealing drain holes in corrosion-proofing

tubular structures. These screws differ from other self-tapping screws in that they are formed to fit screwdrivers and are not intended to be removed after installation. Drive screws are installed by driving the screw into a drilled hole with a hammer.

d. Electrical Screws. Use roundhead machine screws, AN508 (fig. 221), for electrical use in such applications as instrument installations where non-magnetic qualities are desired.

e. Wood Screws. Wood screws, AN545 and AN550 (fig. 222), and self-tapping screws are



DASH NUMBER	LENGTH	GRIP
-6	3/8	1/32
-7	7/16	1/16
-8	1/2	1/8
-9	9/16	5/32
-10	5/8	7/32
-11	11/16	9/32
-12	3/4	11/32
-14	7/8	15/32
-16	1	19/32

DASH NUMBER FOR THE 1/4-28 SCREW IS PRECEDED BY 416-. EXAMPLE: AN525-416-6

SIZE AND THREAD	DIAMETER	HEAD DIAMETER	HEAD THICKNESS
NO. 8-32 (NF-3) NO. 8-36 (NF-3)	0.164 + 0.000 - 0.002	0.312	0.087 ± 0.005
NO. 10-32 (NF-3)	0.190 + 0.000 - 0.002	0.375	0.094 ± 0.005
1/4-28 (NF-3)	0.250 + 0.000 - 0.002	0.437	0.101 ± 0.005

NOTES:

1. EXAMPLES OF PART NUMBERS:

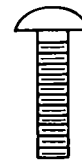
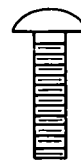
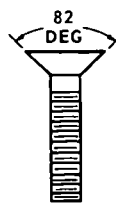
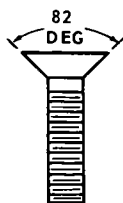
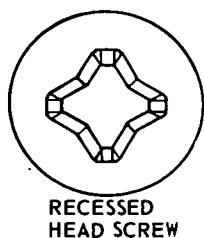
AN525-8-7 - NO. 8-32 NC-3 NICKEL STEEL SCREW, 7/16-INCH LONG, 1/16-INCH GRIP.
AN525D8-7 - NO. 8-32 NC-3 ALUMINUM ALLOY SCREW, 7/16-INCH LONG, 1/16-INCH GRIP.

2. DIMENSIONS SHOWN ARE IN INCHES.

Figure 216. AN525 washer head screws.

used in wood structures only. Both roundhead and 82-degree, countersunk, flathead screws are

available. These screws are manufactured in steel or brass.



SIZE	DIAMETER	THREADS PER INCH		AN505	AN507	AN510	AN515	AN520	AN526
NO. 0	0.060	NF-2	80			X		X	
		NC-2							
NO. 1	0.073	NF-2	72			X		X	
		NC-2							
NO. 2	0.086	NF-2	64			X		X	
		NC-2	56	X			X		
NO. 3	0.099	NF-2	56			X		X	
		NC-2	48	X			X		
NO. 4	0.112	NF-2	48		X	X		X	
		NC-2	40	X	X		X		
NO. 5	0.125	NF-2	44			X		X	
		NC-2	40	X			X		
NO. 6	0.138	NF-2	40		X	X		X	X
		NC-2	32	X	X		X		X
NO. 8	0.164	NF-2	36		X	X		X	X
		NC-2	32	X	X		X		X
NO. 10	0.190	NF-2	32		X	X		X	X
		NC-2	24	X	X		X		X
1/4	0.250	UNF-2	28		X	X		X	X
		UNC-2	20	X	X		X		X
5/16	0.313	UNF-2	24		X				
		UNC-2	18	X	X		X		
3/8	0.375	UNF-2	24		X				
		UNC-2	16	X	X		X		

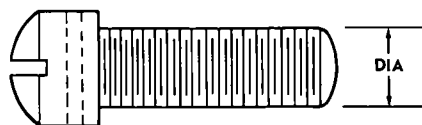
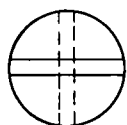
NOTES:

1. ADD R BETWEEN FIRST AND SECOND DASH NUMBERS FOR RECESSED-HEAD SCREWS.
2. ADD B BEFORE FIRST DASH NUMBER FOR BRASS SCREWS WITH BLACK OXIDE FINISH.
3. ADD PB BEFORE FIRST DASH NUMBER FOR CADMIUM PLATED BRASS SCREWS.
4. ADD UB BEFORE FIRST DASH NUMBER FOR PLAIN BRASS SCREWS.
5. ADD C BEFORE FIRST DASH NUMBER FOR CORROSION-RESISTANT STEEL SCREWS.
6. ADD DD BEFORE FIRST DASH NUMBER FOR ALUMINUM ALLOY SCREWS.
7. EXAMPLES OF PART NUMBERS:

AN505-4R8 - NO. 4-40 RECESSED-HEAD, CARBON STEEL SCREW, 1/2-INCH LONG.
 AN507B428R8 - 1/4-28 RECESSED-HEAD, BRASS SCREW WITH BLACK OXIDE FINISH, 1/2-INCH LONG.
 AN510PB4R8 - NO. 4-48 RECESSED-HEAD, CADMIUM PLATED BRASS SCREW, 1/2-INCH LONG.
 AN515UB4R8 - NO. 4-40 RECESSED-HEAD, PLAIN BRASS SCREW, 1/2-INCH LONG.
 AN520C10R8 - NO. 10-32 RECESSED-HEAD, CORROSION-RESISTANT STEEL SCREW, 1/2-INCH LONG.
 AN526DD1032R8 - NO. 10-32 RECESSED-HEAD, ALUMINUM ALLOY SCREW, 1/2-INCH LONG.

8. DIMENSIONS SHOWN ARE IN INCHES.

Figure 217. Machine screws.



				AN500	AN501	AN502	AN503
				1. SAE 1010 CARBON STEEL, 60000 PSI TENSILE STRENGTH 2. CORROSION-RESISTANT STEEL 3. BRASS		STEEL, 8630 125000 PSI TENSILE STRENGTH	
				COARSE THREAD	FINE THREAD	FINE THREAD	COARSE THREAD
SIZE	DIAMETER	THREADS PER INCH	DRILL DIAMETER	CLASS 2 FIT		CLASS 3 FIT	
NO. 2	0.860	56	0.031	X			
NO. 3	0.099	48	0.037	X			
NO. 4	0.112	40	0.037	X			
NO. 5	0.125	40	0.046	X			
NO. 6	0.138	32	0.046	X			X (SEE NDTE 1.)
NO. 8	0.164	32	0.046	X			X (SEE NOTE 1.)
NO. 10	0.190	24	0.046	X			
		32	0.046		X	X (SEE NOTE 1.)	
1/4	0.250	20	0.062	X			X (SEE NOTE 2.)
		28	0.062		X	X (SEE NDTE 2.)	
5/16	0.3125	18	0.070	X			X (SEE NOTE 2.)
		24	0.070		X	X (SEE NOTE 2.)	
3/8	0.375	16	0.070	X			
		24	0.070		X		

NOTES:

1. 3/64-INCH GRIP.
2. 1/16-INCH GRIP.
3. DASH NUMBERS REPRESENT LENGTH IN ONE-SIXTEENTH OF AN INCH. AN500 AND AN501 ONLY:
ADD A FOR DRILLED HEAD, D FOR CORRSION-RESISTANT STEEL, AND B FOR BRASS.
4. DIMENSIONS SHOWN ARE IN INCHES.

Figure 218. Fillister head screws.

Table 45. Hole Sizes for AN504 Screws

Hardest material tapped	Screw size No.	Thickness of hardest material tapped									
		0.015 to 0.018 incl	0.018 to 0.040 incl	0.041 to 0.056 incl	0.057 to 0.071 incl	0.072 to 0.089 incl	0.091 to 0.110 incl	0.108 to 0.115 incl	0.118 to 0.137 incl	0.132 to 0.148 incl	Over 0.148
		Drill holes for screws to diameters specified below									
STEEL	Carbon mild quarter-hard (55,000 psi min TS).	4-24	0.086	0.091	0.096	0.099	0.101				
		6-20	0.104	0.106	0.111	0.116	0.120		0.128		
		8-18	0.116	0.116	0.128	0.136	0.140		0.149	0.149	0.152
		10-16	0.144	0.144	0.144	0.152	0.157		0.161	0.169	0.169
		14-14	0.185	0.185	0.191	0.199	0.204		0.209	0.228	0.228
	Chrome-molybdenum normalized (90,000 psi min TS). (See note 1.)	4-24	0.080	0.091	0.096	0.099	0.101				
		6-20	0.110	0.110	0.116	0.120	0.120	0.128			
		8-18	0.128	0.128	0.136	0.136	0.140	0.144		0.149	
		10-16	0.154	0.154	0.154	0.157	0.161	0.160		0.169	0.169
		14-14	0.191	0.191	0.191	0.199	0.214	0.209		0.228	0.228
	Corrosion-resistant half-hard (150,000 psi min TS). (See note 1.)	4-24	0.091	0.093	0.099						
		6-20	0.110	0.110	0.116	0.116					
		8-18	0.128	0.128	0.136	0.140	0.144				
		10-16			0.157	0.161	0.166	0.169			
		14-14			0.191	0.199	0.204	0.209	0.213	0.228	
	Aluminum-magnesium-chrome half-hard (34,000 psi min TS)	4-24	0.086	0.086	0.091	0.096	0.099				
		6-20	0.104	0.104	0.106	0.111	0.116				
		8-18	0.116	0.116	0.116	0.128	0.136			0.149	
		10-16	0.144	0.144	0.144	0.144	0.152			0.161	0.169
		14-14	0.180	0.185	0.185	0.191	0.199			0.209	0.218
ALUMINUM ALLOY	Aluminum-copper-magnesium-manganese heat-treated (52,000 psi min TS).	4-24	0.086	0.086	0.091	0.096	0.096	0.099			
		6-20	0.104	0.104	0.106	0.106	0.111	0.113			
		8-18	0.116	0.116	0.116	0.128	0.128	0.136		0.116	
		10-16	0.144	0.144	0.144	0.144	0.152	0.152		0.140	
		14-14	0.185	0.185	0.185	0.191	0.199	0.204		0.157	0.161
	Aluminum-copper magnesium (1.5%)-manganese heat-treated (62,000 psi min TS)	4-24	0.086	0.086	0.086	0.091	0.096				
		6-20	0.104	0.104	0.106	0.106	0.111				
		8-18	0.116	0.116	0.116	0.128	0.128				
		10-16	0.144	0.144	0.144	0.149	0.152				
		14-14	0.185	0.185	0.185	0.191	0.199				
	Castings (aluminum alloy or aluminum).	4-24				0.099	0.101	0.101			
		6-20				0.116	0.120	0.120	0.128		
		8-18				0.144	0.144	0.144	0.149	0.149	0.149
		10-16				0.157	0.157	0.157	0.161	0.169	0.169
		14-14				0.191	0.199	0.204	0.209	0.221	0.228

Note 1. Lubricate with heavy cutting oil.

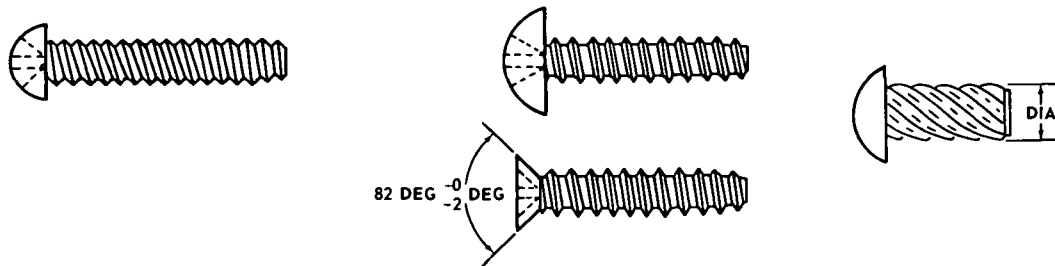
Note 2. Dimensions shown are in inches.

Table 46. Hole Sizes for MS Screws

	Screw size No.	Thickness of hardest material tapped									
		0.015 to 0.018 incl	0.018 to 0.040 incl	0.041 to 0.056 incl	0.057 to 0.071 incl	0.072 to 0.089 incl	0.091 to 0.110 incl	0.108 to 0.115 incl	0.118 to 0.137 incl	0.132 to 0.143 incl	Over 0.148
		Drill holes for screws to diameters specified below									
STEEL	Carbon mild quarter-hard (55,000 psi min. TS).	4-40	0.086	0.086	0.086	0.093	0.093	.....	0.096	0.096	0.096
		6-32	0.104	0.104	0.104	0.113	0.113	.....	0.113	0.120	0.120
		8-32	0.128	0.128	0.128	0.140	0.140	.....	0.140	0.144	0.144
		10-24	0.149	0.149	0.149	0.154	0.154	.....	0.154	0.161	0.161
		1/4-28	0.199	0.199	0.199	0.209	0.209	.....	0.209	0.213	0.213
	Chrome-molybdenum normalized (90,000 psi min TS). (See note 1.)	4-40	0.089	0.089	0.089	0.089	0.096	0.098	.....	0.098	
		6-32	0.110	0.110	0.110	0.110	0.116	0.120	.....	0.120	
		8-32	0.136	0.136	0.136	0.136	0.140	0.144	.....	0.144	
		10-24	0.157	0.157	0.157	0.157	0.159	0.161	.....	0.161	
		1/4-28	0.209	0.209	0.209	0.209	0.213	0.218	.....	0.218	0.218
	Corrosion-resistant half-hard (150,000 psi min TS). (See note 1.)	4-40	0.093	0.093	0.096						
		6-32	0.110	0.110	0.110	0.116					
		8-32	0.136	0.136	0.140	0.144	0.144				
		10-24	.....	.....	0.159	0.161	0.161	0.166			
		1/4-28	.....	.....	0.205	0.205	0.209	0.213	0.218	0.221	
ALUMINUM ALLOY	Aluminum-magnesium-chrome half-hard (34,000 psi min TS).	4-40	0.086	0.086	0.086	0.086	0.089	.....	.....	0.093	
		6-32	0.104	0.104	0.104	0.104	0.106	.....	.....	0.106	
		8-32	0.128	0.128	0.128	0.128	0.136	.....	.....	0.140	
		10-24	0.149	0.149	0.149	0.149	0.152	.....	.....	0.154	
		1/4-28	0.193	0.193	0.199	0.199	0.204	.....	.....	0.204	
	Aluminum-copper-magnesium-manganese heat-treated (52,000 psi min TS)	4-40	0.086	0.086	0.086	0.086	0.089	0.089	.....	0.093	
		6-32	0.104	0.104	0.104	0.104	0.106	0.106	.....	0.106	
		8-32	0.128	0.128	0.128	0.128	0.136	0.140	.....	0.140	
		10-24	0.149	0.149	0.149	0.149	0.152	0.152	.....	0.154	
		1/4-28	0.193	0.199	0.199	0.199	0.204	0.204	.....	0.204	
	Aluminum-copper-magnesium (1.5%)-manganese heat-treated (62,000 psi min TS).	4-40	0.086	0.086	0.086	0.089	0.089				
		6-32	0.104	0.104	0.104	0.109	0.109				
		8-32	0.129	0.129	0.129	0.136	0.136				
		10-24	0.149	0.149	0.149	0.152	0.152				
		1/4-28	0.199	0.199	0.199	0.203	0.203				
	Castings (aluminum alloy or aluminum)	4-40	.....	.....	.....	0.096	0.096	0.096	0.096	0.098	0.098
		6-32	.....	.....	.....	0.116	0.116	0.116	0.116	0.120	0.120
		8-32	.....	.....	.....	0.144	0.144	0.144	0.144	0.147	0.147
		10-24	.....	.....	.....	0.161	0.161	0.161	0.161	0.166	0.166
		1/4-28	.....	.....	.....	0.221	0.221	0.221	0.221	0.228	0.228

Notes.

1. Lubricate with heavy cutting oil.
2. Dimensions shown are in inches.



PART NUMBER	AN504 SELF-TAPPING	MACHINE SCREWS	MS24619 THROUGH MS24622 AND MS24639 THROUGH MS24642 SHEET METAL SCREWS	AN535 DRIVE SCREW	
SIZE	DIAMETER	THREADS PER INCH	DIAMETER	DIAMETER	DRILL SIZE
NO. 00				0.060 0.057	NO. 55 (0.052)
NO. 0				0.075 0.072	NO. 51 (0.067)
NO. 2			0.088 0.084	0.100 0.097	NO. 44 (0.086)
NO. 4	0.112	40	0.114 0.110	0.116 0.112	NO. 37 (0.104)
NO. 6	0.138	32	0.139 0.135	0.140 0.136	NO. 31 (0.120)
NO. 8	0.164	32	0.166 0.161	0.167 0.162	NO. 27 (0.144)
NO. 10	0.190	32	0.189 0.183	0.182 0.177	NO. 20 (0.161)
NO. 12				0.212 0.206	NO. 11 (0.191)
NO. 14				0.242 0.236	NO. 2 (0.221)
1/4	0.250	28	0.246 0.240		

NOTES:

1. AN504 SELF-TAPPING SCREWS HAVE RECESSED HEADS, MS24619 THROUGH MS24622 SHEET METAL SCREWS HAVE RECESSED HEADS, AND MS24639 THROUGH MS24642 SHEET METAL SCREWS HAVE SLOTTED HEADS.
2. DIMENSIONS SHOWN ARE IN INCHES.
3. THE LAST DASH NUMBER FOR ALL SCREWS INDICATES LENGTH IN SIXTEENTHS OF AN INCH.
4. ADD C BEFORE FIRST DASH NUMBER FOR CORROSION-RESISTANT STEEL SCREWS.
5. ADD R BETWEEN FIRST AND SECOND DASH NUMBERS FOR RECESSED HEAD SCREWS.
6. EXAMPLES OF PART NUMBERS:

AN504-4-8 = NO. 4-40, CARBON STEEL, SLOTTED HEAD SCREW, 8/16 IN. LENGTH.
 AN504-4R8 = NO. 4-40, CARBON STEEL, RECESSED HEAD SCREW, 8/16 IN. LENGTH.
 AN504C4-8 = NO. 4-40, CORROSION-RESISTANT STEEL, SLOTTED HEAD SCREW, 8/16 IN. LENGTH.
 AN504C4R8 = NO. 4-40, CORROSION-RESISTANT STEEL, RECESSED HEAD SCREW, 8/16 IN. LENGTH.

Figure 219. Self-tapping screws.

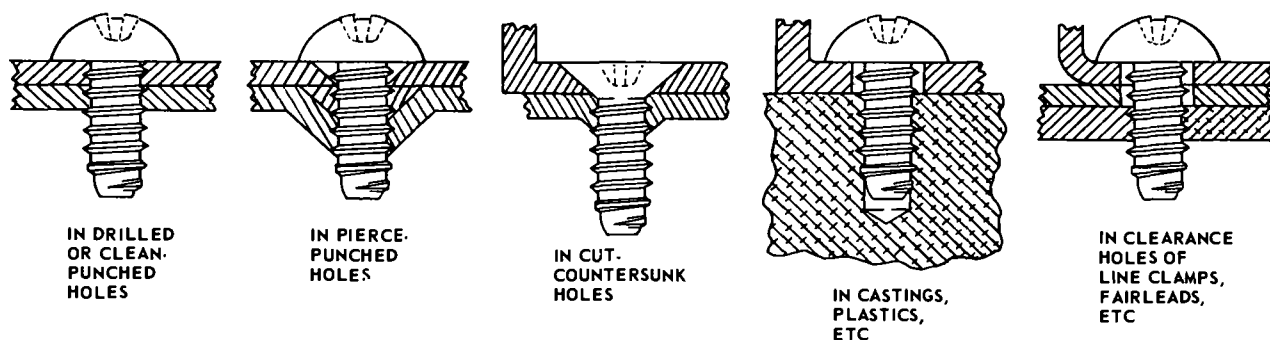
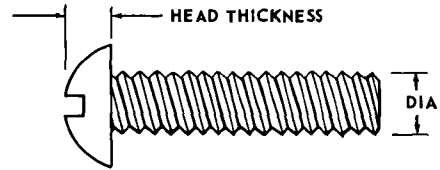
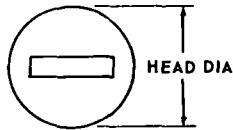


Figure 220. Screw application.



SIZE	THREADS PER INCH	DIAMETER	HEAD DIAMETER	HEAD THICKNESS
NO. 4	40 NC-2	0.112	0.202 ± 0.009	0.081 ± 0.006
NO. 6	32 NC-2	0.138	0.250 ± 0.010	0.097 ± 0.006
NO. 8	32 NC-2	0.164	0.298 ± 0.011	0.113 ± 0.006
NO. 10	32 NF-2	0.190	0.347 ± 0.012 - 0.013	0.130 ± 0.006

LENGTH	DASH NUMBER			
	4	6	8	10
1/8	4-2			
3/16	4-3	6-3	8-3	10-3
1/4	4-4	6-4	8-4	10-4
5/16	4-5	6-5	8-5	10-5
3/8	4-6	6-6	8-6	10-6

NOTES:

1. EXAMPLE OF PART NUMBER:

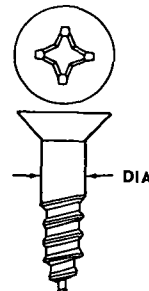
AN508-6-3 – NO. 6 PLATE BRASS SCREW, 3/16-INCH LONG.

2. DIMENSIONS SHOWN ARE IN INCHES.

Figure 221. AN508 roundhead machine screw.



AN545



AN550

SIZE	NO. 2	NO. 3	NO. 4	NO. 5	NO. 6	NO. 8	NO. 10	NO. 12	NO. 14	NO. 16
DIA +0.004 -0.007	0.086	0.099	0.112	0.125	0.138	0.164	0.190	0.216	0.242	0.268

NOTES:

1. MATERIALS: BRASS AND LOW CARBON STEEL.
2. ADD R BETWEEN FIRST AND SECOND DASH NUMBER FOR RECESSED-HEAD SCREWS.
3. ADD B BEFORE FIRST DASH NUMBER FOR BRASS.
4. EXAMPLES OF PART NUMBERS:
AN54S-10R10 – NO. 10 RECESSED-HEAD STEEL SCREW, 1-1/4 INCHES LONG.
AN54SB10R11 – NO. 10 RECESSED-HEAD BRASS SCREW, 1-1/4 INCHES LONG.
5. DIMENSIONS SHOWN ARE IN INCHES.

Figure 222. Wood screws.

Section VII. TURNLOCK FASTENERS

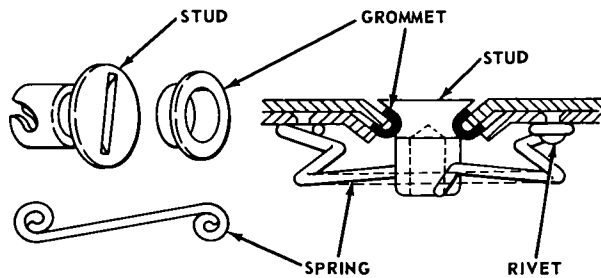
126. Description and Types

Turnlock fasteners are extensively used in aircraft construction. There are many locations on the aircraft which must be accessible for necessary inspections and maintenance of the various aircraft components. Turnlock fasteners make it possible for quick and easy removal or installation of the cowling, fairings, inspection plates, and access doors. Turnlock fasteners are not designed to carry primary structural stresses. Three basic types of turnlock fasteners used by the Army are the Dzus, Camloc, and Airloc.

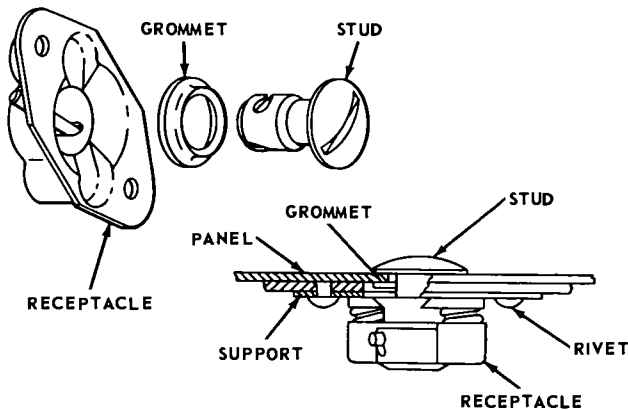
a. Dzus Fastener (Stud, Grommet, and Spring). This type Dzus turnlock fastener consists of a stud, grommet, and a spring. Figure 223 illustrates an installed fastener with its various parts.

(1) The grommet is made of aluminum or aluminum alloy material. It acts as a holding device for the stud. Grommets may be fabricated from 1100 aluminum tubing if none are available from normal sources.

(2) The spring is made of cadmium-plated steel to prevent corrosion. The spring supplies the force that locks or secures the stud in place when two assemblies are joined.



DZUS FASTENER (STUD, GROMMET, AND SPRING)



DZUS FASTENER (STUD, GROMMET, AND RECEPTACLE)

Figure 223. Dzus fasteners.

(3) Studs are fabricated from cadmium-plated steel. They are available in three head styles: flush, flush wing, and oval (fig. 224). Studs are available in different lengths. Stud length is measured in hundredths of an inch and is the distance from the head of the stud to the bottom of the spring hole.

b. Dzus Fastener (Stud, Grommet, and Receptacle). This type Dzus turnlock fastener consists of a stud, grommet, and receptacle. Figure 223 illustrates an installed fastener with its various parts.

(1) The grommet is made of 1100-H14 aluminum, not anodized. The grommet holds the stud in the panel.

(2) The receptacle has a heat-treated steel base and cadmium plated music wire springs. Receptacles are available in two types, rigid and floating. The receptacle is fully inclosed to protect fastener parts and has a smooth, beveled entrance to guide the stud into the locking position. The two coil springs used in the receptacle to provide locking tension have unlimited fatigue value.

(3) The stud is made of SAE 2317 nickel steel, heat treated and cadmium plated. The stud is available in either oval, oval wing, or flush head (fig. 224). A quarter-turn of the stud locks or opens the fastener. The stud is available in different lengths for different thicknesses of material. The stud is held in the panel by a grommet, spring, or ring.

c. Camloc Fastener. Camloc turnlock fasteners are made in a variety of styles and designs. Included among the most commonly used are the 2600, 2700, 40S51, and 4002 series in the regular line, and the stresses-panel fastener (SPF) in the heavy-duty line. The latter is used in stressed panels; that is, panels which carry structural loads. The Camloc turnlock fastener is used primarily to secure aircraft cowling and fairing. It consists of three parts: a stud assembly, a grommet, and receptacle or a stud and receptacle only. This fastener is often referred to as the Camloc cowling fastener. Figure 225 illustrates the 4002-series fastener which consists of a stud, grommet, and receptacle.

(1) The receptacle is riveted to the access opening frame, which is attached to the structure of the aircraft. The grommet is a flanged sheet metal ring made to fit into a plain, dimpled, countersunk or counterbored hole in the external cowling. The type hole to use depends upon location and thickness of the material involved. The grommet is held in the material by

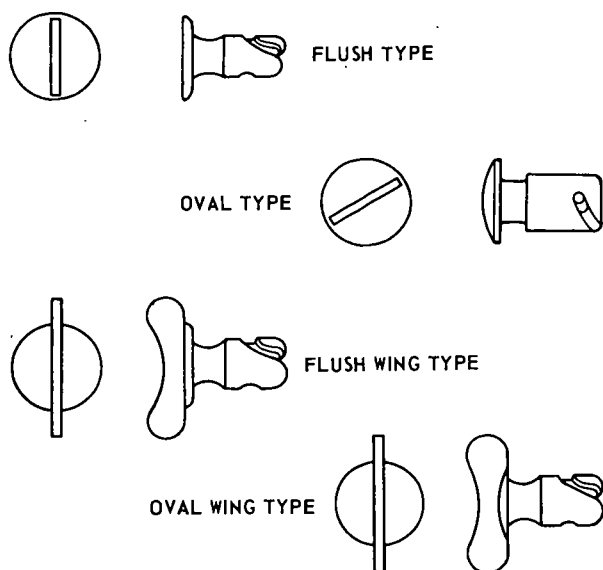


Figure 224. Dzus fastener studs.

a snapping. In addition to serving as a grommet for the hole in the cowling, it also holds the stud assembly. The grommet is furnished in different lengths for varying thicknesses of cowling.

(2) The stud assembly consists of a stud, cross pin, spring, and spring cup. It is preassembled at the factory and should never be disassembled. The stud assembly is manufactured in different lengths to accommodate different thicknesses of panels. The stud may be either a flush or nonflush type.

d. *Airloc Fastener*. The Airloc turnlock fastener consists of three parts: a stud, a cross pin, and a stud receptacle (fig. 226).

(1) The stud is made from casehardened steel to prevent excessive wear. The hole in the shank of the stud is reamed for a press fit of the cross pin. Studs are available in different lengths and are manufactured in three head styles: flush, oval, and wing.

(2) The cross pin is manufactured from chrome vanadium steel and heat-treated to provide maximum strength, wear, and holding. It should never be used the second time; once removed from the stud, it should be replaced with a new cross pin.

(3) Stud receptacles are fabricated from high carbon heat-treated steel. An upper wing assures ejection of the stud when unlocked and enables the cross pin to be held in a locked position between the upper wing, cam, stop, and wing detent, regardless of the tension to which the receptacle is subjected. The receptacle is fastened to the inner surface of the inner sheet to which it is to be attached.

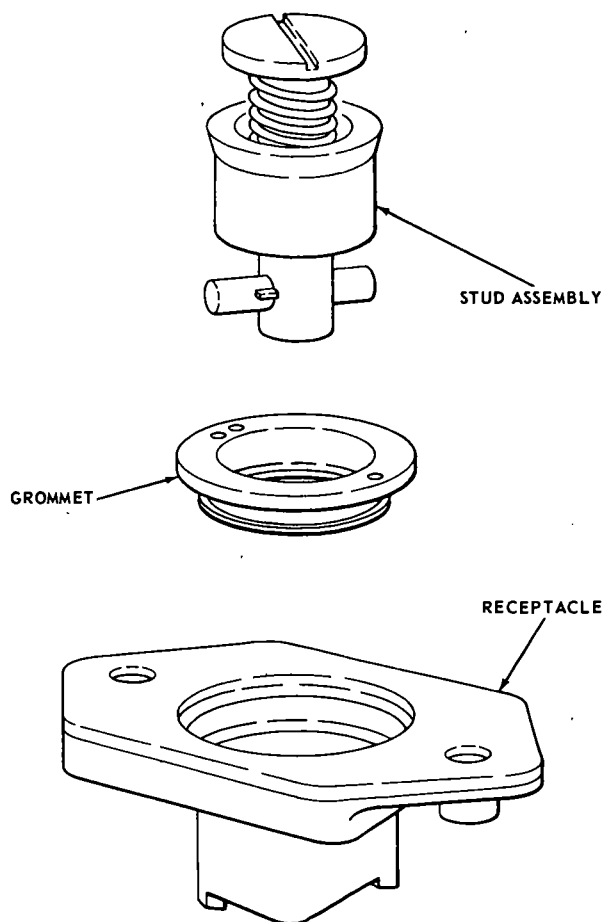


Figure 225. Camloc 4002-series fastener.

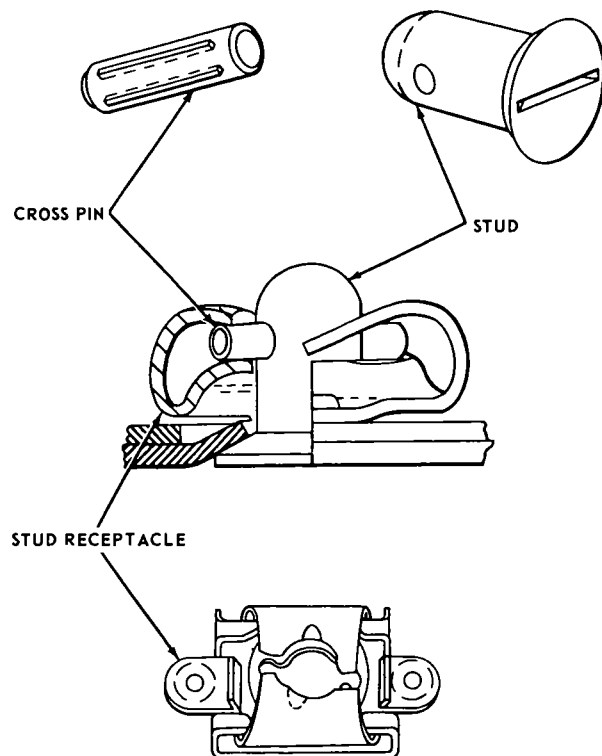


Figure 226. Airloc fastener.

127. Identification

a. *Dzus Fastener (Stud, Grommet, and Spring)*. This type Dzus fastener is available in different sizes and different head designs. The following information will be helpful in understanding the system used for identifying this type Dzus fasteners:

(1) *Studs*. Studs are designated by the letters A, F, FA, and HF. These letters indicate shape of the stud head. The letter A indicates that the head is oval; the letters F and FA indicate that the head is flush; and the letters HF indicate that the head is hexagon. If the letter J is added after these symbols, it indicates that the stud has a longer undercut below the head which allows the stud to eject or recede from the panel when attaching or removing it. The letter W added after these symbols indicates that a wing is attached to the head. The letter O after these symbols indicates that the stud is not undercut, which permits removal of the stud when unlocked. The first figure after the letters indicates body diameter in sixteenths of an inch, and the number following the dash indicates length in hundredths of an inch. A few examples follow:

(a) A3-20 = Oval head stud, 3/16-inch body diameter, 0.20 inch long.

(b) FJ4-35 = Flush head stud, long undercut, 1/4-inch body diameter, 0.35 inch long.

(c) FAW5-35 = Flush head stud, wing attached to head, 5/16-inch body diameter, 0.35 inch long.

(d) AO6 1/2-50 = Oval head stud without undercut, 13/32-inch body diameter, 0.50 inch long.

Note. Body diameter, length, and head type are marked on the heads of the studs.

(2) *Springs*. All standard springs are designated by the letter S. The number following this letter indicates size of the stud with which the spring is used. The number after the dash indicates height of the spring. *For example*, a type S3-200 spring is a standard spring for use with a No. 3 stud and has a height of 0.200 inch.

(3) *Grommets*. All standard grommets carry designations similar to springs except that they are prefixed by the letters GA and GF.

b. *Dzus Fastener (Stud, Grommet, and Receptacle)*. This type Dzus fastener is available in different sizes and head designs. The following information will be helpful in understanding the system used for identifying this type Dzus fastener:

(1) *Studs*. Studs are designated by the letters A, AW, and F. These letters indicate shape of the stud head. The letter A indicates that the head is oval; the letters AW indicates that the

head is oval with a wing; the letter F indicates that the head is flush. Three sizes of body diameters are supplied; 7/32 inch (size 3 1/2), 5/16 inch (size 5), and 3/8 inch (size 6). The first figure following the type letter indicates the body diameter of the stud in sixteenths of an inch. The letter T and the following suffix number indicates total thickness (in hundredths of an inch) of the panel and support for which the fastener is suitable. A few examples follow:

(a) A3 1/2T12 = Oval head stud, 7/32-inch body diameter, suitable for total material thickness of 0.12 inch.

(b) F5T16 = Flush head stud, 5/16-inch body diameter, suitable for total material thickness of 0.16 inch.

(c) AW6T18 = Oval wing head stud, 3/8-inch body diameter, suitable for total material thickness of 0.18 inch.

(2) *Receptacles*. Receptacles are available in two types: type R, rigid and type RF, floating. The numeral following the letter R or RF indicates the body diameter of the stud with which the receptacle is used. A few examples follow:

(a) R3 1/2 = Rigid receptacle for use with A3 1/2, AW3 1/2, or F3 1/2 stud.

(b) RF5 = Floating receptacle for use with A5, AW5, or F5 stud.

Note. Two spacers are supplied with each RF receptacle.

(3) *Grommets*. The stud retaining grommets are designated type GH. The next numeral indicates the body diameter of the stud with which it is used. A few examples follow:

(a) GH3 1/2 = Grommet used with A3 1/2, AW3 1/2, or F3 1/2 stud.

(b) GH5 = Grommet used with A5, AW5, or F5 stud.

(c) GH6 = Grommet used with A6, AW6, or F6 stud.

c. *Camloc Fasteners*. Camloc fasteners are available in different series. Each series is designed for a specific use. The following series are those used in aircraft structural repairs:

(1) The 2600 series is used where a flush fit is not required. The stud will withstand tension and shear loads up to 300 pounds.

(2) The 2700 series is used where a flush fit is required. The stud will withstand tension and shear loads up to 300 pounds.

(3) The 28F series is designed for use where internal clearance conditions are very close. The stud will withstand tension and shear loads up to 300 pounds.

(4) The 4002 series is used where a flush fit is not required and where the possibility of misalignment between panels may be as great

as 1/16 inch. The stud will withstand tension and shear loads up to 1050 pounds.

d. Airloc Fasteners. Airloc fasteners are available in three different sizes: No. 2, No. 5, and No. 7. The size is based on the center-to-center distance between the rivet holes of the receptacle: No. 2, 3/4 inch; No. 5, 1 inch; and No. 7, 1 3/8 inch. For the correct stud shank diameter and stud cross pin length to be used with the different sizes of receptacles, refer to table 47.

Table 47. Sizes of Airloc Fasteners

Size	Stud shank diameter	Stud cross pin length
No. 7 (1 3/8 in.).....	5/16 in.	0.600 in.
No. 5 (1 in.).....	17/64 in.	0.453 in.
No. 2 (3/4 in.).....	11/64 in.	0.313 in.

Note. The total thickness of material that a stud will satisfactorily lock together is stamped on the head of the stud in thousandths of an inch.

128. Installation and Removal Instructions

The following are typical procedures for installing and removing the different types of turnlock fasteners:

a. Dzus Fastener Installation (Stud, Grommet, and Spring). Using the special tools shown in figure 227, install dzus fasteners, type A-AJ and F-FA-FJ, as shown in figure 228.

b. Dzus Fastener Installation (Stud, Grommet and Receptacle). Using the special tools shown in figure 229, install receptacle as shown in figure 230 and stud and grommet (or spring or ring) as shown in figure 231.

c. Dzus Fastener Removal. Dzus fasteners will be removed as follows:

(1) Centerpunch heads of rivets securing spring or receptacle. Using a drill slightly smaller than diameter of rivet shank, drill through rivet head. With a hammer and chisel, remove rivet head from rivet shank. Drive rivet shank from the hole with a punch. Remove the spring or receptacle.

(2) Remove stud from grommet by driving it through grommet using a wooden block or mallet.

(3) Remove grommet from hole by cutting with a chisel or similar tool.

d. Camloc Fastener Installation. Camloc fasteners will be installed as follows:

(1) Prepare a hole in the panel or piece of material that is to receive grommet. The hole should be punched approximately 1/32 inch smaller than outside diameter of grommet. The edges should be deburred and sanded smooth to avoid cracking during dimpling operations.

(2) Select male and female dimpling dies of correct size to dimple the hole.

(3) Insert grommet into dimpled hole from the top and expand snapping over the shoulder of the grommet.

(4) Using a pair of Camloc pliers, depress spring of the stud assembly; then, with a twisting motion, insert stud into grommet and release spring. The stud cannot be removed unless spring is again depressed.

(5) Prepare a hole in the piece of material that is to receive the receptacle. The hole should be approximately the same diameter as that in the receptacle.

(6) Center receptacle on prepared hole and mark rivet locations. Remove receptacle from hole. Centerpunch, drill, and countersink rivet holes.

(7) Install receptacle on hole and secure with flush head style rivets.

e. Camloc Fastener Removal. Camloc fasteners will be removed as follows:

(1) Centerpunch heads of rivets securing receptacle. Using a drill slightly smaller than diameter of rivet shank, drill through rivet head. With a hammer and chisel, remove rivet head from rivet shank. Drive rivet shank from the hole with a punch. Remove the receptacle.

(2) Using Camloc pliers, depress spring of the stud assembly and then, with a twisting motion, remove the stud assembly.

(3) Remove grommet from the panel by cutting it out with a pair of cutting pliers. Be careful not to tear or enlarge hole in the panel.

f. Airloc Fastener Installation. Airloc fasteners will be installed as follows:

(1) Prepare a hole in the panel or piece of material that is to receive the stud. The size of the hole should be approximately the same diameter as the shank of the stud that is to be used. Remove all burs from edge of hole and sand smooth.

(2) Select correct size male and female dimpling dies and dimple the hole. The dimple should be deep enough to accommodate the head of the stud.

(3) Insert stud in dimpled hole. Install cross pin in stud shank using the proper size tool.

(4) Punch a hole in the opposite piece of metal for the receptacle. This hole should be large enough to accommodate the dimple on the opposite piece of material.

(5) Center receptacle on hole. Locate and mark holes for the rivets. Remove receptacle from hole. Centerpunch, drill, and countersink the rivet holes.

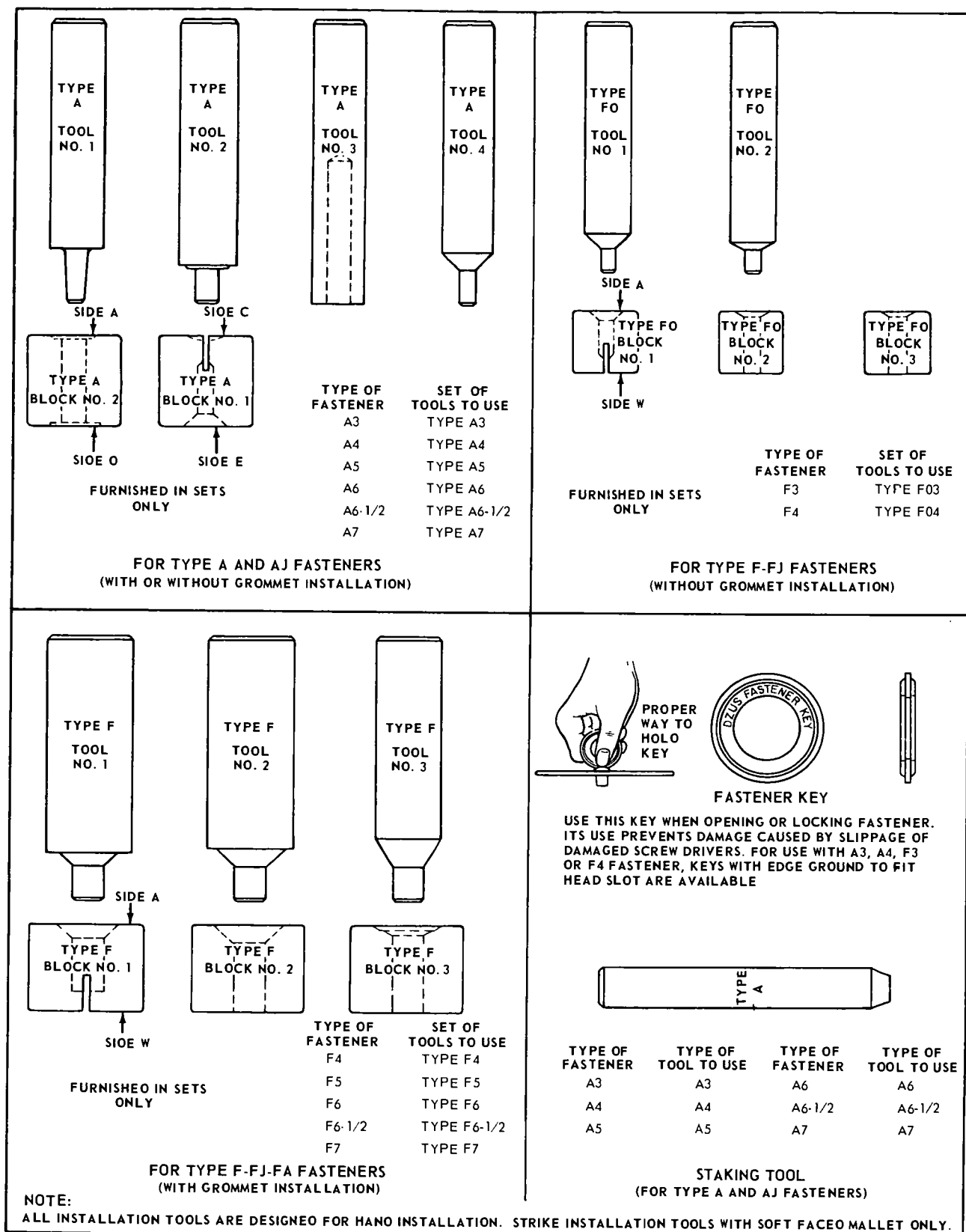


Figure 227. Installation tools for type A-AJ and F-FA-FJ dzus fasteners.

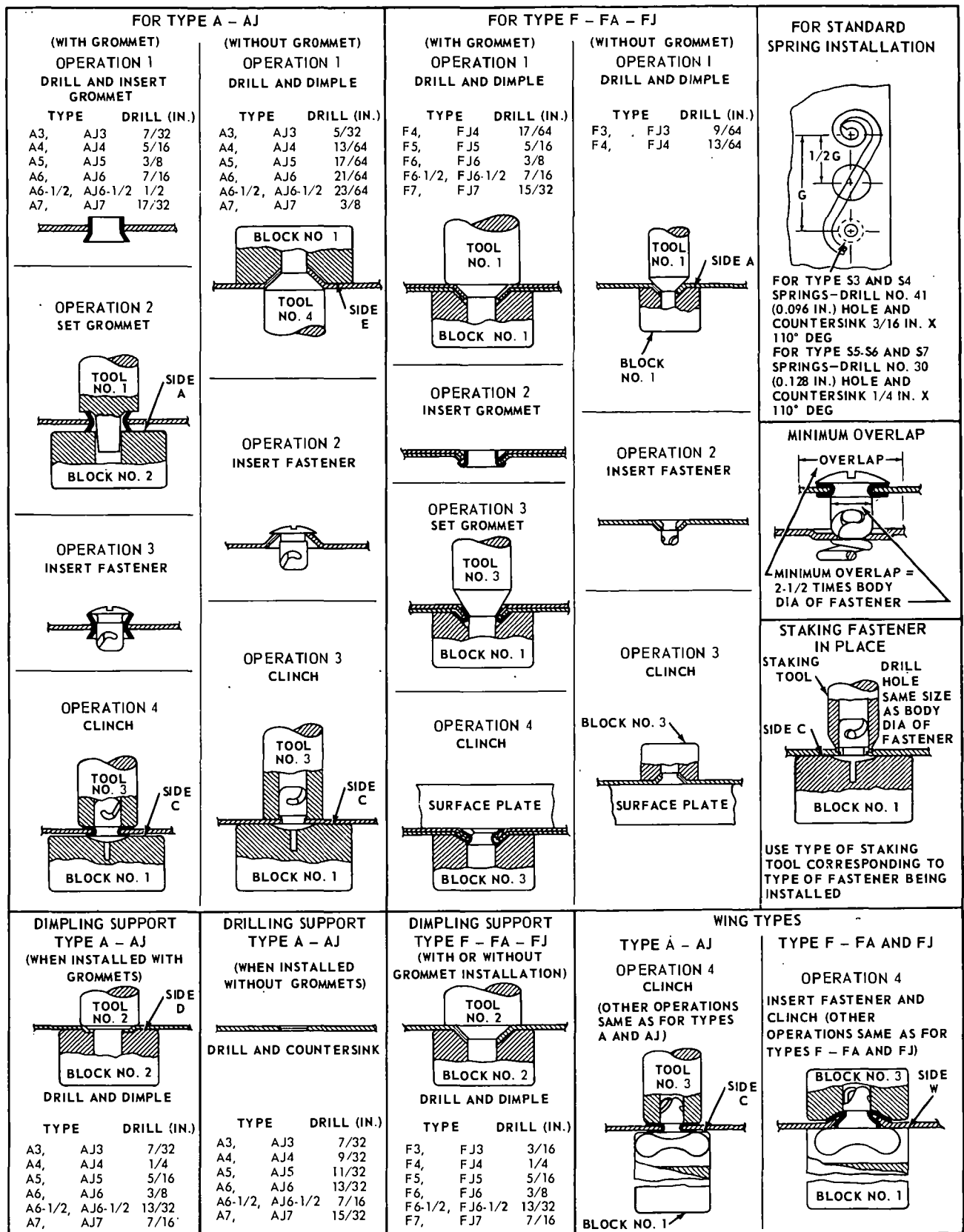
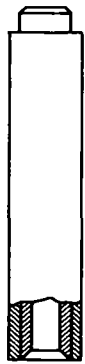


Figure 228. Type A-AJ and F-FA-FJ dzus fastener installation.

TYPE GH HALF GROMMET INSTALLATION TOOLS

FOR FLUSH HEAD STUD

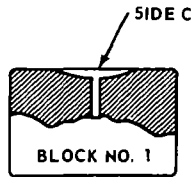
FOR OVAL HEAD STUD



TYPE FH



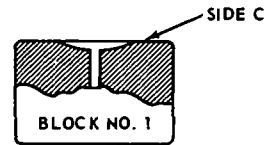
TOOL NO. 5



BLOCK NO. 1

RETAINING RING AND SPRING INSTALLATION TOOLS

FOR OVAL HEAD STUD



BLOCK NO. 1



TYPE OF STUD	SET OF TOOLS TO USE
F3-1/2	FH3-1/2
F5	FH5
F6	FH6

TYPE OF STUD	USE TOOL NO. 5 AND BLOCK NO. 1 FOR TYPE
A3-1/2	A3-1/2
A5	A5
A6	A6

TYPE OF STUD	TOOL NO.	USE BLOCK NO. 1 FOR TYPE
A3-1/2	FR5T3-1/2	A3-1/2
A5	FR5T5	A5
A6	FR5T6	A6

NOTE:

ALL INSTALLATION TOOLS ARE DESIGNED FOR HAND INSTALLATION - STRIKE INSTALLATION TOOL 5 WITH SOFT FACED Mallet ONLY.

Figure 229. Installation tools for stud, grommet, and receptacle.

TYPE R, RIGID RECEPTACLE

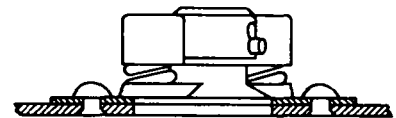
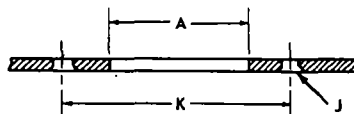
A DRILL HOLES AND COUNTERSINK RIVET HOLES

B RIVET RECEPTACLE

TYPE OF STUD	A ±0.010 (IN.)	K ±0.005 (IN.)	J (IN.)
A3-1/2 F3-1/2	0.468	0.750	0.096
A5 F5	0.703	1.000	0.128
A6 F6	0.812	1.375	0.128

NOTE:

SEE CHART FOR HOLE DIAMETERS AND RIVET HOLE SPACING.



TYPE RF, FLOATING RECEPTACLE

A DRILL HOLES AND COUNTERSINK RIVET HOLES

B PLACE SPACERS IN RECEPTACLE HOLES

C RIVET RECEPTACLE

NOTE:

SEE CHART FOR HOLE DIAMETERS AND RIVET HOLE SPACING.

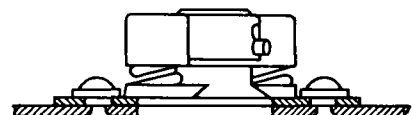
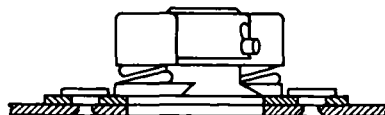
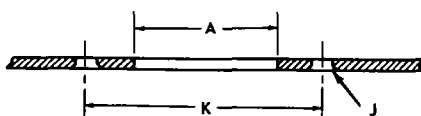
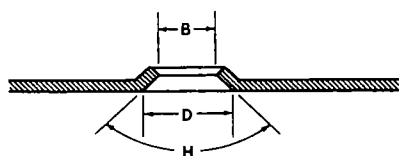


Figure 230. Receptacle installation.

FLUSH HEAD INSTALLATION WITH GH HALF GROMMET

A DRILL AND DIMPLE HOLE IN PANEL

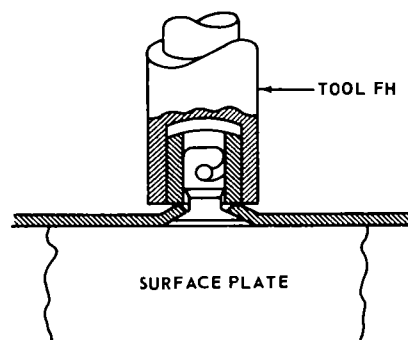
TYPE OF STUD	DIA OF HOLE BEFORE DIMPLING (IN.)	B ± 0.010 -0.000 (DIA OF HOLE AFTER DIMPLING) (IN.)	D ± 0.010 -0.000 (IN.)	H : 2 DEG
F3-1/2	0.189	0.218	0.406	100 DEG
F5	19/64	0.312	0.640	120 DEG
F6	23/64	0.375	0.710	120 DEG



B INSERT STUD AND SLIP GROMMET OVER STUD



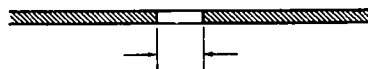
C FLATTEN GROMMET



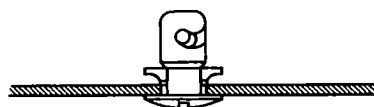
OVAL HEAD INSTALLATION WITH GH HALF GROMMET

A DRILL HOLE IN PANEL

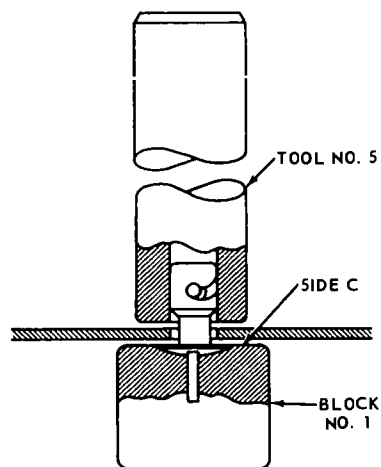
STUD TYPE	HOLE DIAMETER
A3-1/2	7/32 IN.
A5	5/16 IN.
A6	3/8 IN.



B INSERT STUD AND SLIP GROMMET OVER STUD



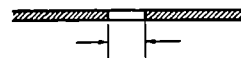
C FLATTEN GROMMET



OVAL HEAD INSTALLATION WITH RETAINING RING AND RETAINING SPRING

A DRILL HOLE IN PANEL

STUD TYPE	HOLE DIAMETER
A3-1/2	7/32 IN.
A5	5/16 IN.
A6	3/8 IN.



B SLIP PLUG INTO STUD-PLACE RING OR SPRING OVER PLUG

NOTE:
FOR EASE OF INSTALLATION A-
ALIGN END OF SPRING OR SPLIT
IN RING WITH UNCUT PORTION
OF STUD (SEE DOTTED LINE)

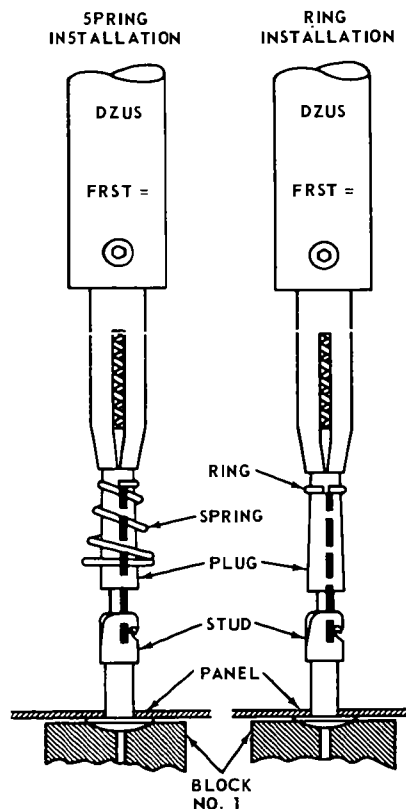


Figure 231. Stud and grommet (or spring or ring) installation.

(6) Install receptacle on hole and secure with countersunk rivets.

g. Airloc Fastener Removal. Airloc fasteners will be removed as follows:

(1) Centerpunch heads of rivets securing receptacle. Using a drill slightly smaller than

diameter of rivet shank, drill through rivet head. With a hammer and chisel, remove rivet head from rivet shank. Drive rivet shank from the hole with a punch. Remove the receptacle.

(2) Remove cross pin from stud using the correct size Airloc tool. Remove the stud.

CHAPTER 9

AIRFRAME REPAIR

Section I. BASIC PRINCIPLES OF REPAIR

129. General

a. Methods of repairing structural portions of an aircraft are numerous and varied, and no set of specific patterns has been found which will apply in all cases. Since design loads acting in various structural parts of an aircraft are not always available to the field repairmen, the problem of repairing a damaged section must usually be solved by duplicating the original part in strength, type of material, and dimensions.

b. The first and one of the most important steps in repairing structural damage in sizing up the job and making an accurate estimate of what is to be done. This sizing up includes an estimate of the best type and shape of patch to use; the type, size, and number of rivets needed; and the strength, thickness, and type of material required to make the repaired member no heavier, or only slightly heavier, and just as strong as the original. The surrounding members must also be inspected for evidence of corrosion and load damage so that an accurate estimate can be made to determine the required extent of the cleanout of the old damage. After completing the cleanout, first make a layout of the patch on paper, then transfer it to the sheet stock selected; then cut and chamfer the patch, form it so it matches the contour of that particular area, and apply the patch.

c. The general principles explained in this chapter are examples of typical repairs associated with the maintenance of aircraft. The procedures in these examples are representative, and when specific manual of instructions is not available, these procedures may be duplicated when applicable. If manual of instructions is available, it will be followed.

130. Maintenance Original Strength

In making any repair, certain fundamental rules must be observed if the original strength of the structure is to be maintained. The patch plate should have a cross sectional area equal to, or greater than, that of the original damaged section.

a. If the member is subjected to compression or to bending loads, place the patch on the outside of the member to secure a higher resistance to such loads. If the patch cannot be placed on the outside of the member, use material one gage thicker than the material used in the original.

b. To reduce the possibility of cracks starting from corners of the cutouts, try to make cutouts either circular or oval in shape. When it is necessary to use a rectangular cutout, make the radius of curvature at each corner no smaller than 1/2 inch. Either replace buckled or bent members or reinforce them by attaching a splice over the affected area.

c. Be sure the material used in all replacements or reinforcements is similar to the material used in the original structure. If it is necessary to substitute an alloy weaker than the original, use material of a heavier gage to give equivalent cross sectional strength. Never practice the reverse; that is, never substitute a lighter gage, stronger material for the original, as one material can have greater tensile strength than another, but less compressive strength than another, but less compressive strength, or vice versa. An example of this is shown in the comparison of mechanical properties of 2024-T4 and 2024-T80 aluminum alloys in *d* below.

d. If aluminum alloy 2024-T4 were to be substituted for aluminum alloy 2024-T80, the substitute material would have to be thicker unless the reduction in compression strength were known to be acceptable. Similarly, the buckling and torsional strength of many sheet metal and tubular parts are dependent primarily upon the thickness rather than the allowable compressive and shear strengths of the material. Therefore, a substitute thinner than the original will reduce considerably the buckling and torsional strength of a part, even though the thinner substitute material has higher compressive and shear strengths.

e. When forming is necessary, be particularly careful. Heat-treated and cold-worked alloys will

stand very little bending without cracking. Soft alloys, on the other hand, are easily formed but are not strong enough for primary structures. Strong alloys can be formed in their annealed condition and heat-treated to develop their strength before assembling.

f. In some cases, if the annealed metal is not available, the metal can be heated, quenched according to regular heat-treating practices, and formed before age hardening sets in. The forming should be completed in about 1/2 hour after quenching or the material will become too hard to work. If a brake is used to form a section, place a thin piece of soft metal over the brake jaws to prevent scraping and scratching the surface of the sheet.

g. The size of rivets to be used for any repair can be determined by referring to the rivets (used by the manufacturer) in the next parallel rivet row inboard on the wing or forward on the fuselage. Another method of determining the size of rivets to be used is to multiply the thickness of the skin by 3 and use the nearest larger size rivet corresponding to that figure. Thus, *for example*, if the skin thickness is 0.040 inch, multiply 0.040 inch by 3, which equals 0.120 inch, and use the next larger size rivet, 1/8 inch (0.125 inch).

h. All repairs made on structural parts of aircraft require a definite number of rivets in order to restore the original strength. This number varies according to the thickness of the material being repaired and the size of the damage. The number of rivets or bolts required can be determined by referring to a similar splice made by the manufacturer, or by using the following rivet formula:

(1) The number of rivets to be used on each side of the break is equal to the length of the break times the thickness of the material times 75,000 divided by the shear strength or bearing strength, whichever is the smaller of the two.

(2) The length of the break is measured perpendicular to the direction of the general stress running through the damaged area.

(3) The thickness of the material is the actual thickness of the piece of material being repaired and is measured in thousandths of an inch.

(4) The 75,000 figure used in the formula is an assumed stress load value of 60,000 psi increased by a safety factor of 25 percent. It is a constant value.

(5) The shear strength is taken from table 30. It is the amount of force required to cut a rivet holding two or more sheets of material

together. If the rivet is holding two parts, it is under single shear; if it is holding three sheets or parts, it is under double shear. To determine the shear strength, the diameter of the rivet to be used must be known. This is determined by multiplying the thickness of the material by 3. An example would be: material thickness of 0.040 inch multiplied by 3 equals 0.120 inch; the rivet diameter selected would be 1/8 inch (0.125 inch).

(6) The bearing strength is taken from table 48. It is the amount of tension required to pull a rivet through the edge of two sheets riveted together, or to elongate the hole. The diameter of the rivet to be used and the thickness of material being riveted must be known to use table 48. The diameter of the rivet would be the same as that used when determining the shear strength value. Thickness of material would be that of the material being repaired.

(1) Once the derivation and meaning of the terms used in the rivet formula is understood, the

Table 48. Bearing Strength (Pounds)

Thickness of sheet (in.)	Diameter of rivet (in.)							
	1/16	3/32	1/8	5/32	3/16	1/4	5/16	3/8
0.014	71	107	143	179	215	287	358	430
0.016	82	123	164	204	246	328	410	492
0.018	92	139	184	230	276	369	461	553
0.020	102	153	205	256	307	410	512	615
0.025	128	192	256	320	384	512	640	768
0.032	164	245	328	409	492	656	820	984
0.036	184	276	369	461	553	738	922	1107
0.040	205	307	410	512	615	820	1025	1230
0.045	230	345	461	576	691	922	1153	1383
0.051	261	391	522	653	784	1045	1306	1568
0.064	...	492	656	820	984	1312	1640	1968
0.072	...	553	738	922	1107	1476	1845	2214
0.081	...	622	830	1037	1245	1660	2075	2490
0.091	...	699	932	1167	1398	1864	2330	2796
0.102	...	784	1046	1307	1569	2092	2615	3138
0.125	...	961	1281	1602	1922	2563	3203	3844
0.156	...	1198	1598	1997	2397	3196	3995	4794
0.188	...	1445	1927	2409	2891	3854	4818	5781
0.250	...	1921	2562	3202	3843	5125	6125	7686
0.313	...	2405	3208	4009	4811	6417	7568	9623
0.375	...	2882	3843	4803	5765	7688	9068	11529
0.500	...	3842	5124	6404	7686	10250	12090	15372

formula can be reduced to
$$\frac{L \times T \times 75,000}{S \text{ or } B}$$

(8) For an example of the use of the formula, determine the number of 2117-T4 rivets needed to repair a break 2 1/4 inches long in material 0.040 inch thick.

(a) Formula:
$$\frac{L \times T \times 75,000}{S \text{ or } B}$$

(b) Information needed:
 $L = 2\frac{1}{4}$ (2.25) inches
 $T = 0.040$ inch

Size of rivet: $0.040 \text{ inch} \times 3 = 0.120$
inch, so rivet must be
 $\frac{1}{8}$ (0.125) inch in di-
ameter

S = 389 pounds (from table XXX)

B = 410 pounds (from table XLIX)

S = 389 pounds which is smaller than
B = 410 pounds

(c) Substitution and result:

$$\frac{2.25 \times 0.040 \times 75,000}{389} =$$

$$\frac{6750}{389} = 17.34 \text{ rivet per side.}$$

(d) Since any fraction must be consid-
ered as a whole number, the actual number of

rivets required would be 18 for each side, or 36
rivets for the entire repair.

131. Maintaining Original Contour

Form all repairs in such a manner that they will
fit the original contour perfectly. A smooth con-
tour is especially desirable when making patches
on the smooth external skin of a fast aircraft.

132. Keeping Weight to a Minimum

Keep the weight of all repairs to a minimum.
Make the size of the patch as small as practicable
and use no more rivets than are necessary. In
many cases, repairs disturb the original bal-
ance of the structure. By adding excessive weight
in each repair, the aircraft may become so un-
balanced that it will require adjustment of the
trim and balance tabs.

Section II. GENERAL STRUCTURAL REPAIR

133. General

a. Aircraft structural members are designed
to perform a specific function or to serve a defin-
ite purpose. In the repair of aircraft, the prime
objective is to restore the damaged part to its
original condition. Very often, replacement is the
only way in which this can be done effectively.
When repair of a damaged part is possible, first
study the part carefully to fully understand its
purpose or function.

b. Strength may be the principal requirement
in the repair of certain structures, while others
may need entirely different qualities. *For exam-
ple*, fuel tanks, floats, and hulls must be pro-
tected against leakage; but cowlings, fairings,
and similar parts must have such properties as
neat appearance, streamlined shape, and acces-
sibility. The function of any damaged part must
be carefully determined so that the repair can
be made to meet the requirements.

134. Inspection of Damage

When making a visual inspection of damage, re-
member that there may be other kinds of dam-
age than those caused by flying missiles from the
exterior, such as flak. A rough landing may over-
load one of the landing gears, causing it to be-
come sprung; this would be classified as load
damage. During inspection and sizing up of the
repair job, consideration must be given to how
far the damage caused by the sprung shock strut
extends to supporting structural members.

a. A shock occurring at one end of a member
will be transmitted throughout its length; there-
fore, inspect closely all rivets, bolts, and attach-
ing structures along the complete member for evi-
dence of damage. Make a close examination for

rivets that have partially failed and for holes
which have been elongated.

b. Another kind of damage to watch for is
that caused by weathering or corrosion. This is
known as corrosion damage. Corrosion damage
of aluminum material can be detected by the
white crystalline deposit that may be found
around loose rivets, scratches, or any portion of
the structure that may be a natural spot for mois-
ture to settle.

c. If visual inspection cannot be made of the
inside skin surfaces without disassembly, inspect
the part by rapping the outside skin in various
places with the knuckles. The presence of severe
corrosion will become evident when light rapping
causes slight dents in the material or causes a
white dust to rise.

135. Inspection for Cracks in Major Structural Members

Neither the existence of suspected cracks nor the
full extent of apparent cracks in major struc-
tural members can be accurately determined by
simple visual inspection. In cases where it is im-
portant that cracks be accurately defined, it is
necessary to employ one of several inspection
methods which makes use of penetrating dyes
that render cracks visible. Because of the vital
importance of major structural members, the ex-
tent of cracks in such members should be deter-
mined by using the dye penetrant inspection pro-
cedure, which is recommended by many aircraft
manufacturers. The materials necessary to per-
form a dye penetrant inspection are available in
the form of a complete inspection kit. Indivi-
dual items for replenishment purposes are also
available. Materials in the kit include dye pene-

trant, dye remover, and dye developer. The inspection procedure is as follows:

a. Remove all paint coatings and surface soils before application of the dye penetrant in order to assure accurate results.

b. After removal of all foreign matter, the surface to be inspected should be given a final cleaning by applying dye remover and wiping the surface with clean cloths. A wet coat of dye penetrant should then be applied and allowed to penetrate for 3 to 15 minutes. Apply the dye penetrant by brushing or swabbing the suspected area.

c. Remove the dye penetrant by applying dye remover. This may be accomplished by first wiping the excess dye penetrant off with a dry cloth followed by a cloth moistened with dye remover. A water rinse may be used, but the parts must be thoroughly dried before application of the dye developer.

d. The dye developer may be applied with a brush or by spraying. In either case, a light, even coating free of runs and laps should be applied. As the developer dries to a smooth, white coating, surface defects will be shown as red indications. The depth of the defects will be indicated by the degree of continued bleeding or spread of the red stains. Cracks will show as red lines. Very tight cracks will show as a series of red dots close together. Scattered dots with no pattern indicate porosity. Because of the sensitivity of the method, evaluation of the indications requires careful judgment.

e. After the flaws have been detected and marked, the developer may be removed by applying dye remover or petroleum solvents.

Warning: These materials are flammable liquids, particularly the developer. Safety precautions must, therefore, be observed. The materials must be applied only in well ventilated spaces away from any possible source of spark and flame. Prolonged breathing of the vapors should be avoided, and the use of protective clothing such as gloves, goggles, and aprons is recommended. Contaminated skin should be cleaned with soap and water. Contaminated clothing should be changed immediately and washed prior to reuse.

136. Classification of Damage

After the extent of damage has been determined, it should be classified in one of the following categories: Negligible damage, damage repairable by patching, damage repairable by insertion, or damage necessitating replacement of parts. In many cases, the availability or lack of repair materials and time are the most important factors in determining whether a part should be re-

paired or replaced. The following is a classification and general description of each type of damage:

a. *Negligible Damage.* A damage which does not affect the structural integrity of the member involved, or a damage which can be corrected by a simple procedure without placing flight restrictions on the aircraft, is classified as negligible damage. Small dents, scratches, cracks, or holes that can be repaired by smoothing, sanding, stop drilling, hammering out, or otherwise repaired without the use of additional materials, fall into this classification.

b. *Damage Repairable by Patching.* A damage repairable by patching is any damage exceeding negligible damage limits which can be repaired by bridging the damaged area of a component with a splice material. The splice or patch material used in internal or riveted and bolted repairs is normally the same type of material as the damaged part, but one gage heavier. In a patch repair, filler plates of the same gage and type of material as that in the damaged component may be used for bearing purposes or to return the damaged part to its original contour.

c. *Damage Repairable by Insertion.* Any damage which can be repaired by cutting away the damaged section, replacing the removed portion with a like section of the damaged component, and securing the insertion with splices at each end is classified as damage repairable by insertion.

d. *Damage Necessitating Replacement of Parts.* Replacement of an entire part is considered when one or more of the following conditions exist:

(1) When a complicated part has been extensively damaged.

(2) When surrounding structure or inaccessibility makes repair impractical.

(3) When damaged part is relatively easy to replace.

(4) When forged or cast fittings are damaged beyond the negligible limits.

137. Corrosion Control

Corrosion control and treatment are of major importance to all aircraft and missile maintenance personnel. They are vital because corrosion of equipment and primary structures can have great effect on the capability and operational and structural integrity of any given aircraft. Economy is another important reason for corrosion control and treatment, as severe corrosion can ultimately weaken primary structures sufficiently to require replacement or reinforcement in order to sustain designated loads. Weakening usually necessitates a major repair that can be

costly, time consuming, and result in loss of aircraft effectiveness. Scheduled inspections and preventive measures are essential to determine aircraft status and to provide for early correction of weakness. Preventive maintenance lessens the total amount of labor used and expense required, and insures that corrosion will not affect the designed performance of the aircraft. Most metals are subject to corrosion, but corrosion can be minimized by use of corrosion-resistant metals and finishes when consistent with weight and strength design factors of the aircraft. The principal corrosion preventive used in air-frame structures is aluminum alloy sheets coated on both sides with pure aluminum. Under normal conditions, alclad aluminum is highly resistant to corrosion; however, accumulated soil, salts, industrial fumes, and moisture will cause pitting of the alclad surface. Nonclad metals require some special preventive measures to guard against corrosion. Aluminum alloys, for example, are usually either anodized or chemically treated and painted. The internal structure of air-frames is usually painted with an organic finish. Steel (except most stainless steels) and metals such as bronze and brass require cadmium or zinc plating, conversion coating, paint, or all three for protection. Magnesium requires special chemical treatments and paint finishes.

a. Types of Corrosion. Corrosion can be defined as the deterioration of a metal by reaction to its environment. The corrosion occurs because of the tendency of most metals to return to their natural state. (Iron, in the presence of moist air, will revert to its natural state, iron oxide.) Metals are also corroded by the direct action of the metal to a chemical.

(1) To better understand the causes and results of the various types of corrosion, consider what happens in electrochemical reaction or corrosion. Four conditions must exist before electrochemical corrosion can occur (fig. 232). These conditions are—

(a) There must be something that corrodes the metal (metal anode).

(b) There must be a cause (cathode).

(c) There must be a continuous liquid path (electrolyte, usually condensate and salt or other contaminations).

(d) There must be a conductor to carry the flow of electrons from the anode to the cathode. This conductor is usually in a form that provides for metal-to-metal contact (rivets, bolts, welds, etc.).

(2) The elimination of any one of the four conditions will automatically stop corrosion. As an example, an organic film applied to the sur-

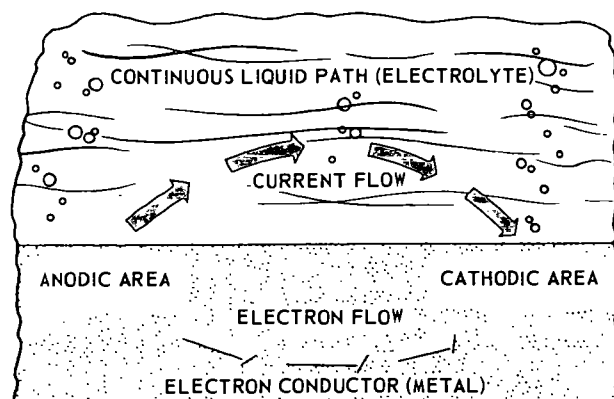


Figure 232. Conditions for electrochemical corrosion.

face of the metal will prevent the electrolyte from connecting the cathode and the anode and the current cannot flow; therefore, no corrosion will occur.

(3) At normal atmospheric temperatures, metals do not corrode appreciably without moisture, but moisture in the air is usually enough to start action. Oxygen is also usually essential for serious corrosion to take place in ordinary water at room temperature. Other factors which affect a metal's tendency to corrode are: acidity or alkalinity of the conductive medium (pH factor); stability of the corrosion products; biological organisms, particularly anaerobic bacteria; variation in composition of the corrosive medium; temperature; etc.

(4) The initial rate of corrosion is usually much greater than the rate after a short time because the oxide film which forms on a metal surface tends to protect the metal underneath. This is not true for stress corrosion.

(5) When aircraft constructed of many different types of metals must perform under highly varied climatic conditions, the corrosion problem becomes complex. The presence of salts on metal surfaces (from sea coast operations or sites, blast deposits after firing guns or JATO bottles, urine spray, spillage of fuel oxidizers, or taxiing over runways where various salts have been used to decrease ice formation) greatly increases the electrical conductivity of any moisture present and accelerates corrosion.

(6) Moisture tends to collect on dirt particles. Maintaining clean surfaces on passive metals or alloys can be of even greater importance than on plain carbon steel or copper base alloy because, if corrosion areas begin to develop, the combination of small active anodes to large passive cathodes causes severe pitting. This principle also applies to metals which have been passivated by chemical treatment as well as to

metals which develop passivation due to environmental conditions (e.g., aluminum and stainless steel).

(7) Alloys that owe their corrosion resistance to passivity are particularly susceptible to accelerated corrosion within crevices. This phenomenon is caused by formation of an oxygen cell resulting from lower oxygen concentration in the crevice. For these reasons, cleanliness must be maintained and corrosion preventive measures must be observed even on corrosion-resistant materials.

(8) Some areas of aircraft are subjected to more corrosive substances than others, and the possibility of a corrosion problem and the necessary control measures vary accordingly. Nearly all corrosive attacks begin on the surface of metal exposed to corrosive environment. If allowed to progress, corrosion works down into the core of the material. Since corrosion never originates in the core, there will always be evidence on the surface when an attack is in progress.

b. Common Types of Corrosion. Corrosion has been cataloged and typed in many ways. For descriptive purposes, the types are discussed under what is considered the most commonly accepted titles.

(1) *Uniform etch corrosion.* The surface effect produced by most direct chemical attacks (as by an acid) is a uniform etching of the metal. On a polished surface, this type of corrosion is first seen as a general dulling of the surface. If such corrosion is allowed to continue, the surface becomes rough and, possibly, frosted in appearance.

(2) *Pitting corrosion.* The most common effect of corrosion on aluminum and magnesium alloys is called pitting. It is first noticeable as a white or gray powdery deposit, similar to dust, which blotches the surface. When the deposit is cleaned away, thin pits or holes can be seen in the surface. Pitting corrosion may also occur in other types of metal alloys.

(3) *Intergranular corrosion.* Intergranular corrosion is an attack on the grain boundaries of a material. A highly magnified cross section of any commercial alloy shows the granular structure of the metal. It consists of quantities of individual grains, and each of these tiny grains has a clearly defined boundary which chemically differs from the metal within the grain center. The adjacent grains of different elements can react with each other as anode and cathode when in contact with an electrolyte (conductive medium). Rapid selective corrosion at the grain boundary can occur.

(4) *Exfoliation corrosion.* Exfoliation is a form of intergranular corrosion. It shows itself by lifting up the surface grains of a metal by the force of expanding corrosion products occurring at the grain boundaries just below the surface. It is visible evidence of intergranular corrosion. It is most often seen on extruded sections where grain thicknesses are usually less than in rolled forms.

(5) *Galvanic corrosion.* Galvanic corrosion occurs when dissimilar metals are in contact and an external circuit is provided by the presence of a buildup of corrosion at the joint between the metals. *For example,* aluminum and magnesium skins riveted together in an aircraft wing form a galvanic couple if moisture and contaminations are present. When aluminum pieces are attached with steel bolts or screws, galvanic corrosion can occur between the aluminum and the steel.

(a) Metals grouped together in table 49 have no strong tendency to produce galvanic corrosion and are relatively safe to use in contact with each other. The coupling of metals from different groups and the distance from each other in the chart will usually result in galvanic

Table 49. Grouping of Metals and Alloys

Group I	Magnesium and its alloys; aluminum alloys 5052, 5056, 5356, 6061, and 6063.
Group II	Cadmium, zinc, and aluminum and their alloys (including the aluminum alloys in group I).
Group III	Iron, lead, and tin and their alloys (except stainless steel).
Group IV	Copper, chromium, nickel, silver, gold, platinum, titanium, cobalt, and rhodium and their alloys; stainless steel and graphite.

Metals classified in the same group are considered similar to each other.

Metals classified in different groups are considered dissimilar to each other.

or accelerated corrosion of the metal higher on the list. The farther apart the metals are in the table, the greater will be the galvanic tendency, as can be determined by measurement of the electrical potential difference between them.

(b) All commonly used metals will cause corrosion of magnesium in strong salt environment. Cadmium or zinc plating on the more cathodic metals, such as iron and steel, will greatly reduce galvanic corrosion. Tin-plated metal, when connected to magnesium, causes less corrosion than cadmium- or zinc-plated metal. This is because, in this unusual circumstance, the tin polarizes and acts as an insulator. This is a contradiction; hence, it must be kept in mind that

the galvanic series of metals and alloys are to be used for general information and that exceptions do exist.

(c) The use of aluminum alloys containing magnesium, such as 5052 and 5053, usually will satisfactorily reduce galvanic corrosion of the magnesium alloys and also reduce simultaneous corrosion of the aluminum. Under severe exposure, when the contact of magnesium alloys and plated steel bolts is necessary, the use of 5052 aluminum washers may prevent severe galvanic attack.

(d) Continuity of the liquid path may also be broken by the use of vinyl or polyester tapes. When conditions favorable to galvanic corrosion are unavoidable, always protect both portions of a couple. A break in the protective coating on the anodic surface will cause severe pitting if the cathodic surface is not protected. This is due to the concentration of current upon the relatively small area exposed.

(e) When practical, rivets, bolts, and other fasteners should be made of the same material as the main structure. When not practical, they should be selected from materials lower in the list in table 49 in order to distribute the anodic attack over the larger of the two coupled metals. This is particularly important where the fasteners are subjected to high stress and where the safety factor is low. However, the structural strength of the aircraft must not be endangered by substituting incorrect parts.

(6) *Concentration cell corrosion.* Concentration cell corrosion occurs when two or more areas of a metal surface are in contact with dif-

ferent concentrations of the same solution. There are three general types of concentration cell corrosion: metal ion concentration cells, oxygen concentration cells, and active-passive cells.

(a) *Metal ion concentration cells.* The solution may consist of water and ions of the metal which is in contact with the water. A high concentration of the metal ions will normally exist under faying (mating on adjoining surfaces) where the solution is stagnant and a low concentration of metal ions will exist adjacent to the crevice which is created by the faying surface. An electrical potential will exist between the two points; the area of the metal in contact with the low concentration of metal ions will be cathodic and be protected, and the area in contact with the high metal ion concentration will be anodic and will be corroded. Figure 233 illustrates metal ion concentration cell corrosion.

(b) *Oxygen concentration cells.* The solution in contact with the metal surface will normally contain dissolved oxygen. An oxygen cell can develop at any point where the oxygen in the air is not allowed to diffuse into the solution, thereby creating a difference in oxygen concentration between two points. Typical locations of oxygen concentration cells are under either metallic or nonmetallic deposits (dirt) on the metal surface and under faying surfaces, such as riveted lap joints. Oxygen cells can also develop under gaskets, wood, rubber, plastic tape, and other materials in contact with the metal surface. Corrosion will occur at the area of low oxygen concentration (anode) as illustrated in figure 233.

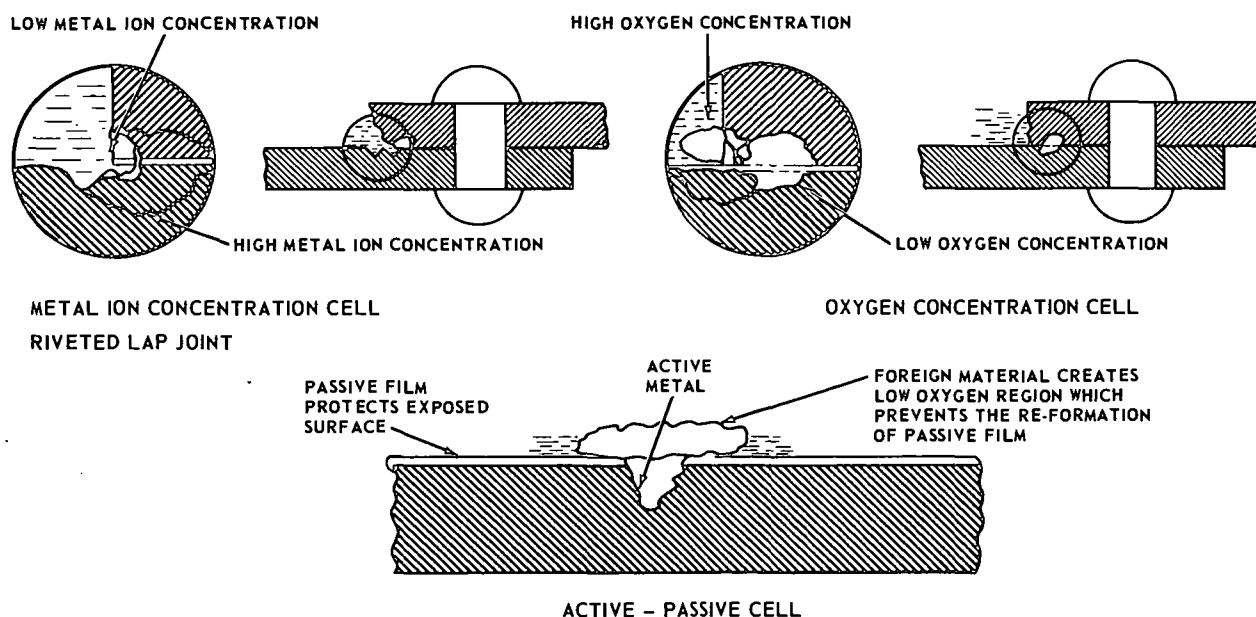


Figure 233. Concentration cell corrosion.

(c) *Active-passive cells.* Metals which depend on a tightly adhering passive film, usually an oxide, for corrosion protection (*for example, austenitic corrosion-resistant steel*), are prone to rapid corrosive attack by active-passive cells. The corrosive action usually starts as an oxygen concentration cell; *for example*, salt deposits on the metal surface in the presence of water containing oxygen can create the oxygen cell. The passive film will be broken beneath the dirt particle for the corrosive action on the oxygen cell. Once the passive film is broken, the active metal beneath the film will be exposed to corrosive attack. An electrical potential will develop between the large area of the cathode (passive film) and the small area of the anode (active metal). Rapid pitting of the active metal will result as illustrated in figure 233.

(7) *Stress corrosion cracking.* Stress corrosion cracking is caused by the simultaneous effects of tensile stress and corrosion. Stress may be internal or applied. Internal stresses are produced by nonuniform deformation during cold working, by unequal cooling from high temperatures, and by internal structural rearrangement involving volume changes. Stresses induced when a piece is deformed, those induced by press and shrink fits, and those in rivets and bolts are internal stresses. Concealed stress is more important than design stress, especially because stress corrosion is difficult to recognize before it has overcome the design safety factor. The magnitude of stress varies from point to point within the metal. Stresses in the neighborhood of the yield strength are generally necessary to promote stress corrosion cracking, but failures have occurred at lower stresses.

(8) *Fatigue corrosion.* Fatigue corrosion is a special case of stress corrosion caused by the combined effects of cyclic stress and corrosion. No metal is immune to some reduction of its resistance to cyclic stressing if the metal is in a corrosive environment. Damage from fatigue corrosion is greater than the sum of the damage from both cyclic stresses and corrosion.

(a) Fatigue corrosion failure occurs in two stages. During the first stage, the combined action of corrosion and cyclic stresses damages the metal by pitting and cracking to such a degree that fracture by cyclic stressing will ultimately occur, even if the corrosive environment is completely removed. The second stage is essentially a fatigue stage in which failure proceeds by propagation of the crack and is controlled primarily by stress concentration

effects and the physical properties of the metal.

(b) Fracture of a metal part due to fatigue corrosion generally occurs at a stress far below the fatigue limit in laboratory test, even though the amount of corrosion is unbelievably small. For this reason, protection of all parts subject to alternating stress is particularly important when practical, even in environments that are only mildly corrosive.

c. *Inspection for Corrosion.* Without proper and systematically performed inspections and maintenance, corrosion will seriously damage any aircraft. All equipment should be carefully inspected at each periodic inspection for signs of corrosion. Typical locations that should be closely inspected are as follows:

- (1) Unpainted aluminum areas.
- (2) Skin seams.
- (3) Lap joints.
- (4) Nicks and crevices where traces of cleaning compound have accumulated.
- (5) Areas where moisture does not evaporate as rapidly as areas exposed to direct sunlight and air.
- (6) Drain holes that may be clogged.
- (7) Structures underneath floorboards.
- (8) Faying surfaces.
- (9) Fittings, braces, and compound parts inside the aircraft where foreign matter or moisture may accumulate because of improper drainage or disposal outlets.
- (10) Areas where dissimilar metals may be in contact.
- (11) Spotwelds.
- (12) Piano-type hinges.
- (13) Exhaust gas paths.
- (14) Wheel wells, landing gear, dive brakes, and similar areas.
- (15) Heavy or tapered aluminum alloy skin surfaces.
- (16) Battery boxes and components.
- (17) Relief tube outlet.

d. *Corrosion Removal and Treatment.* Corrosion can be removed from metals by using either the chemical method or the mechanical method. These methods for removal and treatment of corrosion are discussed in TM 55-1500-204-25/1.

138. Stresses in Structural Members

Forces acting on an aircraft, whether it is on the ground or in flight, cause pulling, pushing, or twisting within the various members of the aircraft structure. While the aircraft is on the ground, the weight of the wings, fuselage, engines, and empennage causes forces to act downward on the wing and stabilizer tips, along the spars and stringers, and on the bulkheads and formers.

These forces are passed on from member to member, causing bending, twisting, pulling, compression, and shearing. The five types of stresses in an aircraft are described as tension, compression, shear, bending, and torsion (or twisting). The first three are commonly called the basic stresses; the last two, the combination stresses. Stresses rarely act singly, but usually in combinations. The most important types of stresses from the standpoint of the metal repairman are bending, torsion, and shear.

a. Tension. Tension (or tensile stress) is the force per unit area tending to stretch a structural member. In figure 234, note the condition of the metal strap before and after stretching. Drilling a hole in the strap removed much of the material and reduced its cross sectional area. Since the load is constant from one end of the strap to the other, and the hole cannot carry any of the load, the stress in the reduced section is greatly increased (per unit area). The area on each side of the hole is carrying not only its normal share of the load, but also that part of the load which should have been carried by the removed material. Obviously, if the load were increased until the strap failed, the break would occur in the material near the hole. The strength of a member in tension is determined on the basis of its gross area (or total area), but calculations involving tension must take into consideration the net area of the member. Net area is defined as the gross area minus that removed by drilling holes or by making other changes in the section. Placing rivets or bolts in holes makes no appreciable difference in added strength, as the rivets or bolts will not transfer tensional loads across holes in which they are inserted.

b. Compression. Compression (or compressive stress) is the force per unit area which tends to shorten (or compress) a structural member at any cross section. Under a compressive load, an undrilled member will be stronger than an

identical member with holes drilled through it. However, if a plug of equivalent or stronger material is fitted tightly in a drilled member, it will transfer compressive loads across the hole, and the member will carry approximately as large a load as if the hole were not there. Thus, for compressive loads, the gross or total area may be used in determining the stress in a member if all holes are tightly plugged with equivalent or stronger material.

c. Shear. Shear is the force per unit area which acts in such a way as to slide adjacent particles of material past each other. The term *shear* is used because it is a sideways stress of the type that is put on a piece of paper or a sheet of metal when it is cut with a pair of shears. Shear stress concerns chiefly from the standpoint of rivet and bolt applications, particularly when attaching sheet stock, for if a rivet used in a shear application gives way, the rivet parts are pushed sideways.

d. Bending. Bending (or beam stress) is actually a combination of two forces acting upon a structural member at one or more points. In figure 234, note that the bending stress causes a tensile stress to act on the upper half of the beam and a compressive stress on the lower half. These stresses act oppositely on the two sides of the centerline of the member, which is called the neutral axis. Since these forces acting in opposite directions are next to each other at the neutral axis, the greatest shear stress occurs along this line, and none exists at the extreme upper or lower surfaces of the beam.

e. Torsion. Torsion (or twisting stress) is the force which tends to twist a structural member. The stresses arising from this action are shear stresses caused by the rotation of adjacent planes past each other around a common reference axis at right angles to these planes. The action may be illustrated by a rod fixed solidly at one end and twisted by a weight placed on a lever arm at the other, producing the equivalent of two equal and opposite forces acting on the rod at some distance from each other. A shearing action is set up all along the rod, with the centerline of the rod representing the neutral axis.

139. General Repair Practices

a. Support of Structure During Repair. It is essential that the structure be firmly supported during repair of any major structural member so that repair work will be completed without any misalignment or distortion. When special fixtures to support the aircraft or any

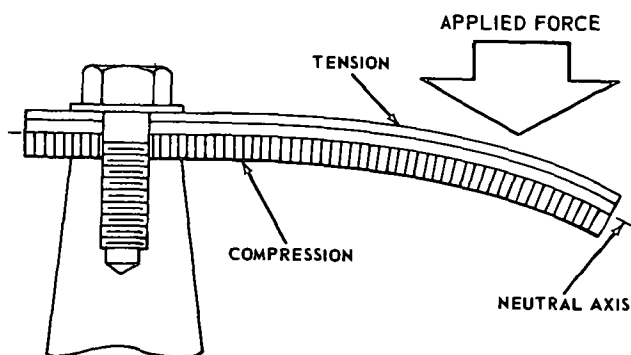


Figure 234. Bending.

of its components are not available, temporary supports should be made.

b. Selection of Repair Material. The first requirement in making a repair is the duplication of the strength of the original structure. The repair material should, therefore, be as strong as that used in the original part. If it is necessary to substitute an alloy weaker than the original, a heavier gage must be used to give equivalent cross sectional strength. Never use a lighter gage material even when using a stronger alloy. Always consult the applicable manual when substituting metals.

c. Layout of Parts for Repair. All new sections made up for repair or replacement of damaged parts in a particular aircraft should be carefully laid out to the dimensions which are given in the applicable manual for that aircraft before fitting the parts into the structure. Care should be taken when marking to prevent scratching the material. Deep scratches may seriously weaken the material and possibly develop into cracks. All marks on aluminum alloy, other than lines to be cut, should be made with a pencil. All contacting surfaces and exposed metal parts of a repair should be, primed with a coating of zinc chromate primer.

d. Selection of Rivets. In general, the rivet size and alloy should be the same as the original rivets in the part being repaired. If a rivet hole has been enlarged or deformed, the next larger size rivet should be used after reworking the hole. When replacement with larger size rivets is made, the proper edge distance for the larger size rivet must be maintained. Where access to the inside of the structure is impossible and blind rivets must be used in making the repair, always consult the applicable manual for the recommended type, size, spacing, and number of blind rivets needed to replace the originally installed rivets or those required for the type repair being installed.

e. Rivet Spacing and Edge Distance. The rivet pattern for a repair must conform with instructions given in the applicable manual. As a general rule, the existing rivet pattern is used when possible. In any case, rivet spacing should never be less than 3D (3 times the diameter of the rivet). Spacing is seldom less than 4D or more than 8D. Edge distance should be at least $2\frac{1}{2}D$ for flush head rivets and at least 2D for all other rivets. An edge distance greater than 4D should never be used.

f. Chemical Milled Skin Repair. The thickness of a chem-milled structural member will vary from end to end, or side to side. Damage of a chem-milled member requires a slightly different

technique for repair. The repair material must be as thick as the thickest part of the chem-milled structure. The repair material is then applied to the thickest part of the damaged member, if practical, using normal riveting procedures. Shimming is then required to fill the gap between the repair material and thin part of the chem-milled structural member. The shim material is secured by rivets thru the damaged part, shim material, and repair material. The techniques for lap patch or flush patch may be used as long as the repair material is secured to the thick part of the chem-milled part.

140. Stressed Skin Repairs

a. Types of Repair. Skin patches may be divided into two general types, the lap or scab patch and the flush patch.

(1) *Lap or scab patch.* A lap patch is an external patch that has the edges of the patch and the skin overlapping each other. The overlapping portion of the patch is riveted to the skin. On some aircraft, lap patches are permitted in certain areas, but only where aerodynamic smoothness is not important.

(2) *Flush patch.* A flush patch consists of a filler patch which is flush with the skin when inserted. It is backed up and riveted to a reinforcement plate which, in turn, is riveted to the inside of the skin. This reinforcement plate is usually referred to on repair diagrams as the *doubler*, or *backup plate*.

b. Open and Closed Skin Areas. One of the factors which determines the exact procedure to be used in making skin repairs is the accessibility to the damaged area and procedures established in the applicable manual. Much of the skin on an aircraft is inaccessible from the inside for making the repair. The skin in such areas is referred to as *closed skin*. Skin that is accessible from both sides as called *open skin*. Repairs to open skin may usually be made in the conventional manner, using specified types of standard rivets, but in repairing closed skin, some type of special fastener must be used. The exact type of fastener used will depend upon the type of repair made and the recommendations of the aircraft manufacturer.

c. Stress Intensity. Another of the important factors to be considered when making a skin repair is the stress intensity of the damaged panel. *For example*, certain skin areas are classified as highly critical, other areas as semicritical, while still other areas may be classified as noncritical. Repairs to damages in highly critical areas must provide 100-percent strength replacement; semicritical areas require 80-percent strength replacement; and

noncritical areas require 60-percent strength replacement. To determine the requirements for making a stressed skin repair, consult the applicable manual for the particular aircraft concerned and follow the instructions therein.

d. Patching Procedures. The following are patching procedures which may be used when performing a repair on the airframe:

(1) *Lap or scab patch.* In areas where it is permitted, the lap patch may be used in repairing cracks, as well as small holes. In repairing cracks, always drill a small hole in each end of the crack before applying the patch. Use a No. 40 drill. Drilling of these holes is important because they prevent the crack from spreading. The patch must be large enough to install the required number of rivets as determined from the rivet schedule indicated for the gage material in the area which is damaged. The recommended patch may be cut circular, square, rectangular, or diamond shaped. The edges must be chamfered to an angle of 45 degrees, and slightly crimped or turned down (fig. 235).

(2) *Flush patch clear of internal structure.* In areas which are clear of internal structure, this type of repair is relatively simple to make. Access for riveting can be obtained in many instances by cutting a hole in the center of the doubler. In inaccessible areas, the flush patch may be made by substituting blind rivets for standard rivets, where permissible, and devising a means of inserting the doubler through the opening. One method is shown in figure 236 in which the doubler has been split. To insert the doubler, slip one edge under the skin and twist the doubler until it slides in place under the skin. The screw in the center hole is temporarily installed to serve as a handle for inserting the doubler through the hole. This type of patch is generally recommended for holes up to 1 1/2 inches in diameter. It is generally more satisfactory to trim holes larger than

1 1/2 inches to a rectangular or square shape, rounding all corners to a generous radius (fig. 237). In all flush patches, the filler should be of the same gage and material as the original skin. The doubler, generally, should be of material one gage heavier than the skin.

(3) *Flush patch over internal structure.* One method of repairing damaged skin over internal structure is shown in figure 238. Two half-round doublers are prepared to fit on each side of the rib. A filler patch brings the surface to the correct contour.

(4) *Sealing of watertight and pressurized areas.* Repairs to hulls and floats often require that the repair be watertight. Also, repairs to pressurized compartments must be sealed against loss of pressure. When possible, the method of sealing should be the same as that used in manufacturing the aircraft. One method recommended by many manufacturers is to clean all contacting surfaces with aliphatic naphtha, and be sure that

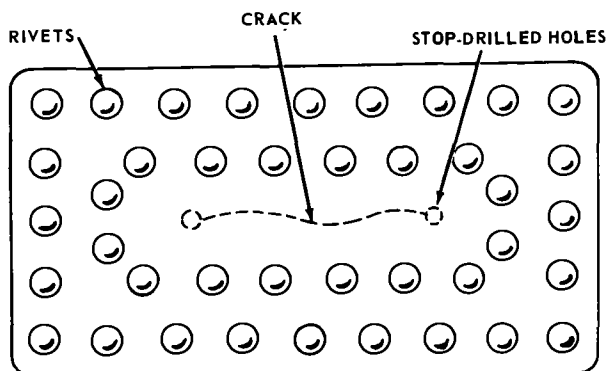


Figure 235. Chamfering and turning edge of patch.

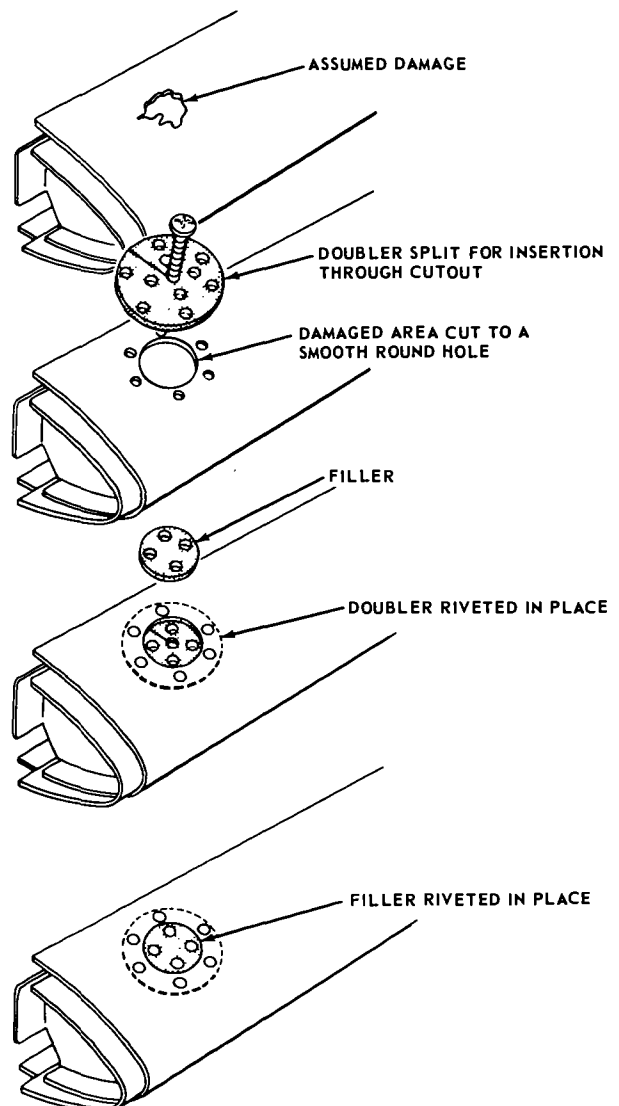


Figure 236. Repair of small holes in skin with flush patch.

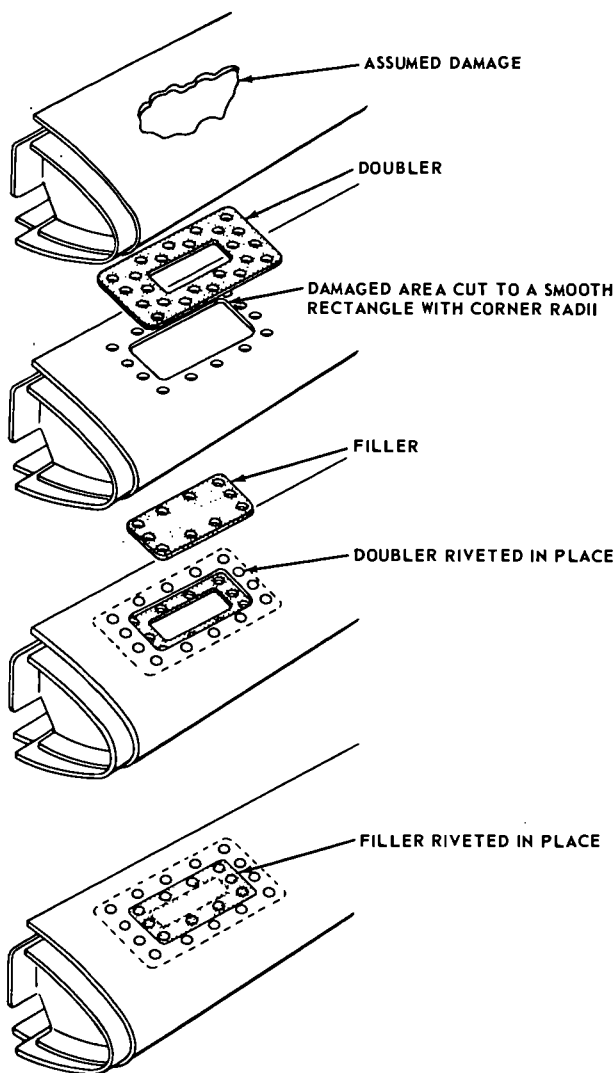


Figure 237. Flush rectangular patch.

all burs, chips, and other foreign materials are removed. Apply zinc chromate sealing tape to both surfaces, and remove the cloth backing strip. Apply a brush coat of zinc chromate paste. Draw the mating surfaces together, using machine screws and nuts. Cleco fasteners do not exert enough pressure and are not to be used. Drive each rivet successively as a screw is removed, and remove excess sealing compound.

(5) *Flush access door.* A flush access door installation (fig. 239) is sometimes permitted.

It is installed to facilitate repair to the internal structure and to repair damage to the skin in certain areas. The flush access door consists of a doubler and a stressed cover plate. A single row of nut plates is riveted to the doubler, and the doubler is then riveted to the skin with two rows of rivets, staggered as shown in figure 239. The cover plate is attached to the doubler with machine screws. When an ac-

cess door is permitted and installed over internal structure, a row of screws should be installed through the cover plate into the internal structural member.

e. Skin Replacement. Sometimes damage to the metal skin is so extensive that an entire panel must be replaced. Also, an excessive number of patches or minor repairs to a section or area may require replacement of the entire panel.

(1) As in all other forms of repair, the first step is to inspect the damaged area thoroughly to determine the extent of damage. Inspect internal structure for damage or signs of strain. Such members when bent, fractured, or wrinkled, must be replaced or repaired. All rivets in the area must be inspected for signs of failure. They may be sheared considerably without visible external evidences of such a

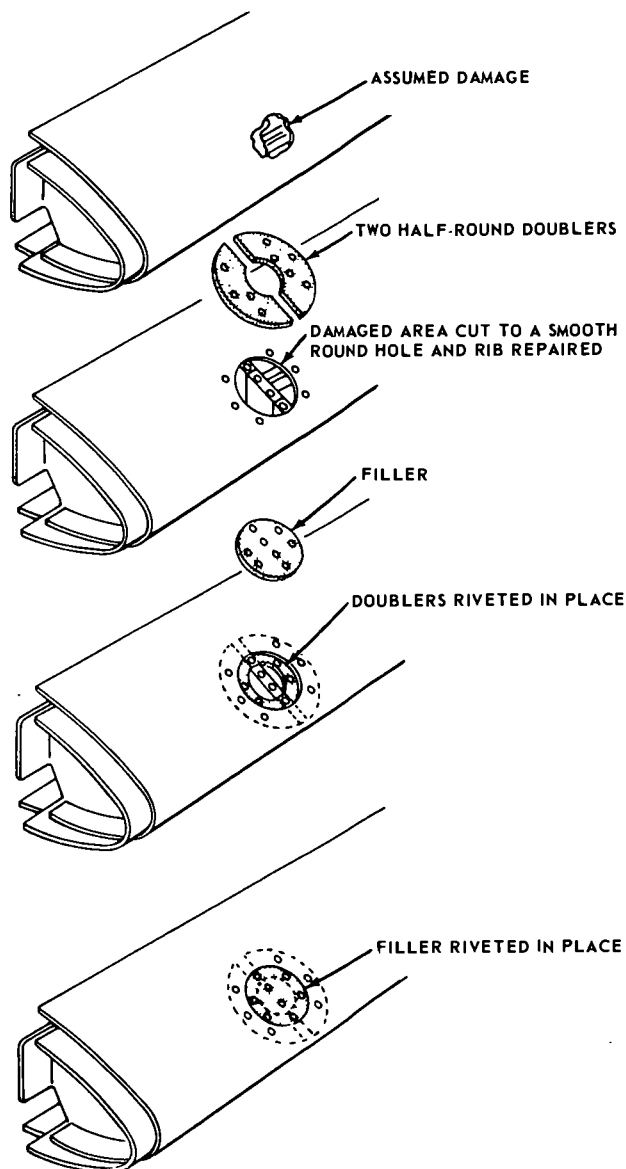


Figure 238. Flush patch over internal structure.

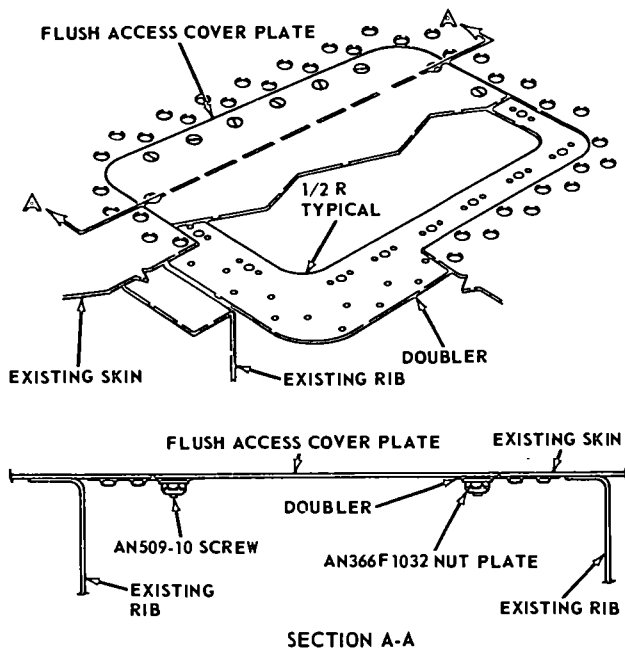


Figure 239. Flush access door.

condition. Drill out rivets at various points in the damaged area and examine them for signs of shear failure.

(2) During inspection, note carefully all unusual riveting problems which render riveting difficult or which make replacement impossible. Any fixtures which will hinder riveting and prevent the use of straight bucking bars will be apparent in a thorough inspection. There will also be places where flanges of reinforcing members, or the intersection of stringers, long-erons and formers, frames, or rings make the bucking of rivets very difficult. This problem can be solved by designing and making bucking bars to suit these particular situations.

(3) Care must be taken to avoid mutilating the damaged skin in the process of removal, because in most cases it can be used as a template for layout and drilling of holes in the new piece of skin.

(4) The rivet holes in stringers, long-erons, bulkheads, formers, frames, rings, and other internal members must be kept in the best condition possible. If any of these members are loosened by the removal of rivets, their locations should be marked so that they can be returned to their original positions when the repair is completed.

(5) Reference should be made to the applicable skin panel diagram in the manual for the specific aircraft for the gage and alloy of material to be used for the replacement panel. The size and shape of the panel may be determined in either of two ways: the dimensions can

be measured during the inspection, or the old skin can be used as a template for the layout of the sheet and the location of the holes, the latter method being preferable and more accurate. Regardless of the procedure used, the new sheet must be large enough to replace the damaged area, and may be cut with an allowance of 1 to 2 inches of material outside the rivet holes.

(6) If the old sheet is not too badly damaged, it should be flattened out and used as a template. The new sheet, having been cut approximately 1 inch larger than the old, should then be drilled near the center of the sheet, using the holes in the old sheet as a guide. The two sheets are then fastened together with sheet metal fasteners. The use of sheet metal screws is not recommended, as they injure the edges of the rivet holes. The drilling should proceed from the center to the outside of the sheet, inserting sheet metal fasteners at frequent intervals.

(7) If impossible to use the old sheet as a template, the holes in the new sheet should be drilled from the inside of the structure, using the holes in the reinforcing members as guides, drilling and inserting fasteners in the same manner as described above. This is called *back-drilling*. Before placing the new sheet on the framework to drill the holes, make certain that the reinforcing members are aligned and flush at the points at which they intersect; otherwise, the holes in the new sheet will not be accurately aligned. For the same reason, the new sheet should have the same contour as the old before drilling the rivet holes.

(8) In duplicating holes from reinforcing members to skin, extreme care must be exercised or both frame and skin will be ruined. Since most bulkheads, ribs, and stringers depend on the skin for some of their rigidity, they can easily be forced out of alignment in the drilling process. The skin must be held firmly against the framework, or the pressure from the drilling will force it away from the frame and cause the holes to be out of alignment. This may be overcome by placing a block of wood against the skin and holding it firmly while the drilling progresses. Also, make sure that the drill is held at a 90-degree angle to the skin at all times, or the holes will be elongated and out of alignment. When drilling through anchor nuts, a smaller pilot drill should be used first. Care must be used to avoid damaging the anchor nut threads. The pilot holes are then enlarged to the proper size.

(9) It may be necessary to use an angle attachment of flexible shaft drill in places where

it is impossible to insert a straight drill. In case neither type can be inserted, the new section can be marked carefully with a soft pencil through the holes in the old section. Another method of marking the location of the new holes is to use a transfer or prick punch as shown in figure 240. Center the punch in the old hole, then hammer lightly on the outside of the sheet with a mallet. The result should be a mark which will serve to locate the hole in the new sheet.

(10) Still another way to locate the rivet holes without a template is to use a hole finder, similar to the one shown in figure 241. This device makes it possible to drill holes in the new section of skin in perfect alignment with the holes in the old section. The hole finder is made in two sections, an upper part and a lower part which are bolted together at one end. At the free end of the bottom section of the hole finder is a guide rivet which drops into the old holes in the sheet still in place. The free end of the top section of the hole finder has a hole in a position which exactly matches the position of the guide rivet, and through this opening the new hole is drilled. Thus, as the hole finder is moved along, the guide rivet drops into an old hole and automatically determines the position of the new hole.

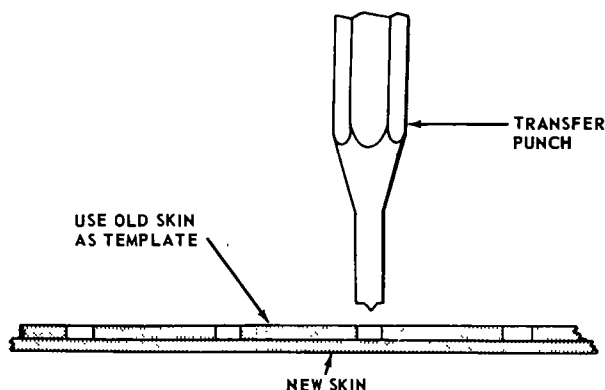


Figure 240. Transfer punch.

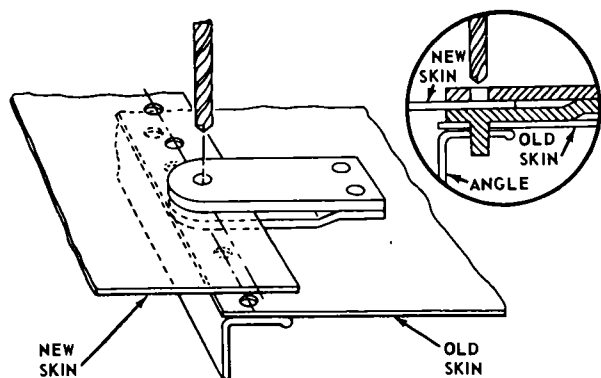


Figure 241. Hole finder.

(11) After all the holes have been drilled, the temporary fasteners are taken out and the sheet is removed from the framework. The burs left by drilling must be removed from both sides of all holes in the skin, stringers, and rib flanges. Deburring may be accomplished with a few light turns of a countersink drill. In this way, particles of metal left around the edges of the drilled holes are eliminated. If they were not removed, the joint would not be tight and rivets might expand, or flash, between the parts being riveted.

(12) The selection of a proper type and weight of bucking bar is an important factor in the success of a riveting job. A bucking bar for 1/8-inch rivets should weigh at least 2 pounds. Bars for larger rivets should be proportionately heavier. A light bar has a tendency to develop a hardened, clinched head because it requires too many blows to upset the rivet.

(13) When possible, use a straight bar so that its weight can be applied directly in line with the shank of the rivet. Where flanges on ribs or stringers will not permit the use of a straight bar, devise one that will allow pressure to be applied in a straight line with the rivet, such as those shown in details (A) and (B) of figure 242. These bucking bars give much better results than one with a beveled end like that in detail (C). Attach the skin in position with enough sheet metal fasteners to hold it firmly in place.

141. Internal Structural Repair

The internal structure of the semimonocoque fuselage is made up of longitudinal (fore and aft) members called longerons and stringers, and vertical members referred to as bulkheads, rings, formers, and frames. The wing, stabilizers, and flight control surfaces are made up of spanwise members called spars and stringers, and chord-

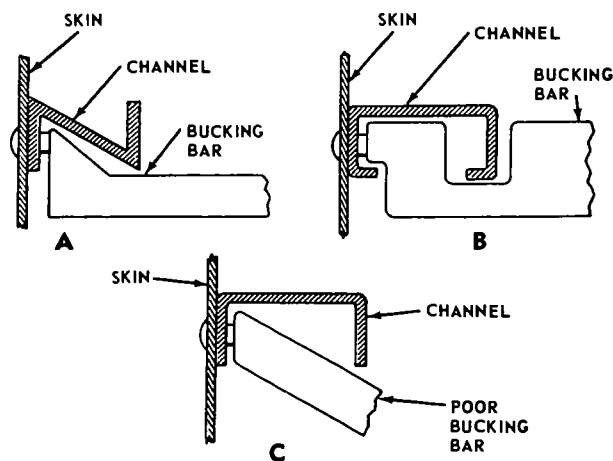


Figure 242. Correct and incorrect bucking bars.

wise members called bulkheads, ribs, and formers. Several typical repairs of these various structural members are discussed in *a* through *g* below:

a. Stringer Repair. A stringer is designed to stiffen the skin and aid in maintaining the contour of the structure. Stringers also transfer stresses from the skin to the bulkheads and ribs to which they are attached. Stringers are not continuous throughout the structure as are longerons, and are not subject to as much stress. Stringers are made from both extruded and rolled sections and are usually in the form of C-channels, angles, or hat sections. Figure 243 illustrates one method used in repairing a damaged stringer by patching. The repair consists of a reinforcement splice and a filler splice. The reinforcement splice should be long enough to extend a minimum of four times the width of the leg of the stringer on each side of the damaged area. The cross sectional area of the reinforcement splice must be equal to or greater than the stringer itself. The damage is cleaned out to a smooth contour with corner radii, and a filler of the proper thickness is prepared to fit in the cleaned out area. If possible, always make both ends of the cutout midway between two rivets, so that the existing rivet pattern can be maintained in the repair. Cut the filler splice $1/32$ inch shorter in length than the cutout section. This will allow $1/64$ -inch clearance between each end of the filler splice and the stub ends of the stringer, thus eliminating any possibility of stress developing from contact between the two parts.

Note. The repair in *a* above is permissible when the damage does not exceed two-thirds of the width of one leg of the stringer, and is not over 12 inches in length. Where damage exceeds two-thirds of the leg width, use the method shown in figure 244. Where the damage is of such length that a single reinforcement splice would involve an excessive amount of material and work, a repair by insertion should be made. See figures 245 and 246.

b. Longeron Repair. Generally, longerons are comparatively heavy members which serve approximately the same function as stringers. Consequently, longeron repair is similar to stringer repair. Because the longeron is a heavy member and more strength is needed than with a stringer, heavy rivets should be used in the repair. Sometimes bolts are used to install a longeron repair, but, because of the greater accuracy required, they are not as suitable as rivets. Also, bolts require more time for installation. If the longeron consists of a formed section and an extruded angle section, consider each section separately. Make the longeron repair using the same procedures as for stringer repair; however, keep the rivet spacing (pitch) between 4- and 6-rivet diameters. If bolts are used, drill the boltholes for a light-drive fit.

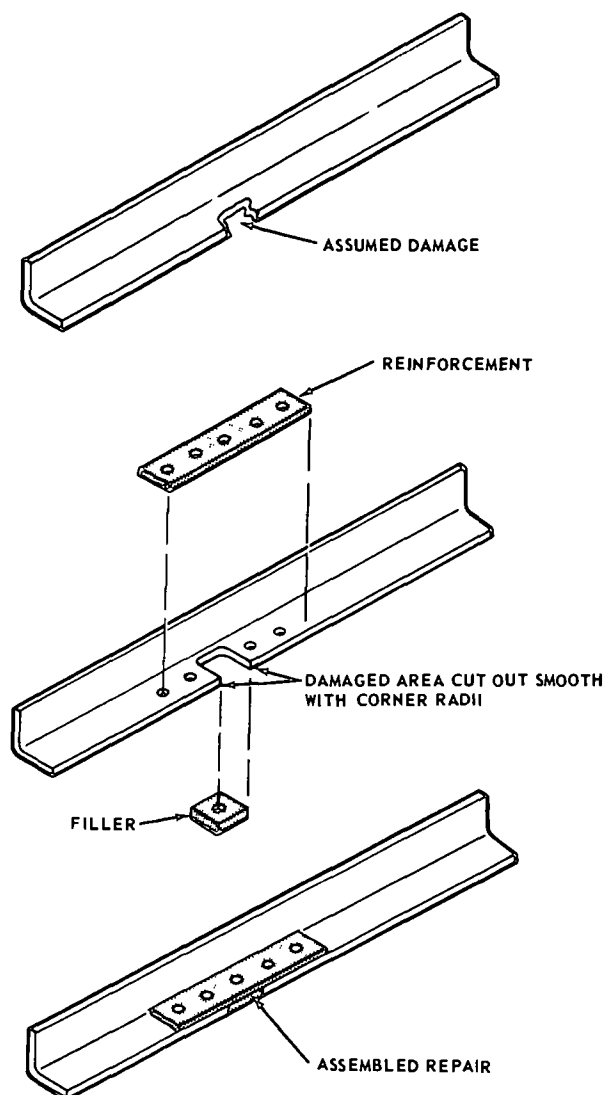


Figure 248. Stringer repair by patching (damage not exceeding two-thirds of one leg width).

c. Spar Repair. Spars, also called beams, are the main spanwise members of the wing, stabilizers, and other airfoils. They may run the entire length of the airfoil, or only part of the length. Spars are designed primarily to take bending loads imposed on the wing or other airfoil. The most common type of spar construction is shown in figure 247, and consists of extruded capstrips, a sheet metal web or plate, and vertical angle stiffeners. Since spars are very highly stressed members, their repair may not be permitted, but if permitted, must be made in strict accordance with instructions given in the applicable manual, using the best possible workmanship. Figure 247 illustrates a spar web repair by insertion.

d. Rib Repair. Ribs are the principal chordwise structural members in the wings, stabilizers, and other airfoils. Ribs serve as formers for

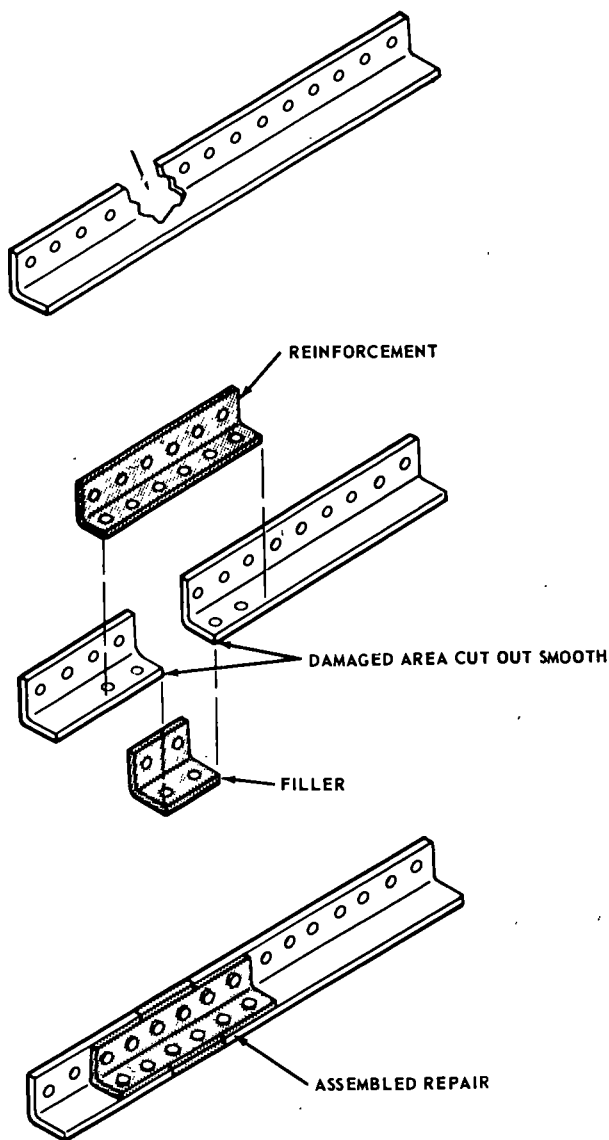


Figure 244. Stringer repair by patching (damage exceeding two-thirds of one leg width).

the airfoil, giving it shape and rigidity, and also serve to transmit stresses from the skin to the spars. They are designed to resist both compression and shear loads. There are three general types of rib construction, reinforced rib, truss rib, and former rib. The reinforced rib and the truss rib are both relatively heavy as compared to the former rib, and are located only at points where the greatest stresses are imposed. Former ribs are located at frequent intervals throughout the airfoil. The reinforced rib is similar in construction to that of spars, consisting of upper and lower capstrips joined by a web plate. The web is reinforced between the capstrips by vertical and diagonal angles. The reinforced rib is much more widely used than the truss rib. The truss rib consists of capstrips reinforced solely by ver-

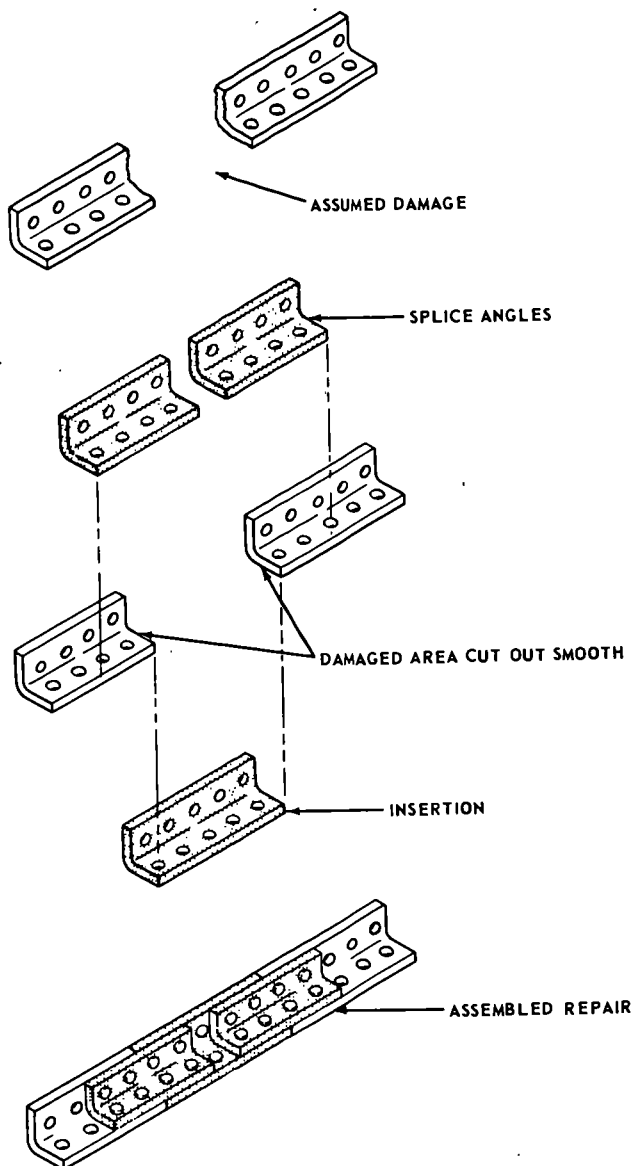


Figure 245. Stringer repair by insertion (damage affecting only one stringer).

tical and diagonal crossmembers. It is used in the wings of some of the larger aircraft. Former ribs are made of formed sheet metal and are very light in weight. The bent-up portion of a former rib is correctly referred to as the flange, and the vertical portion is called the web. The web is generally constructed with lightening holes, with beads formed between the holes. The lightening holes lessen the weight of the rib without decreasing the strength. Rigidity of lightening hole areas is accomplished by flanging the edges of the lightening holes. The beads stiffen the web portion of the rib. Rib repair by patching is illustrated in figure 248. Figure 249 shows an example of rib repair by insertion.

e. *Former or Bulkhead Repair.* Bulkheads are

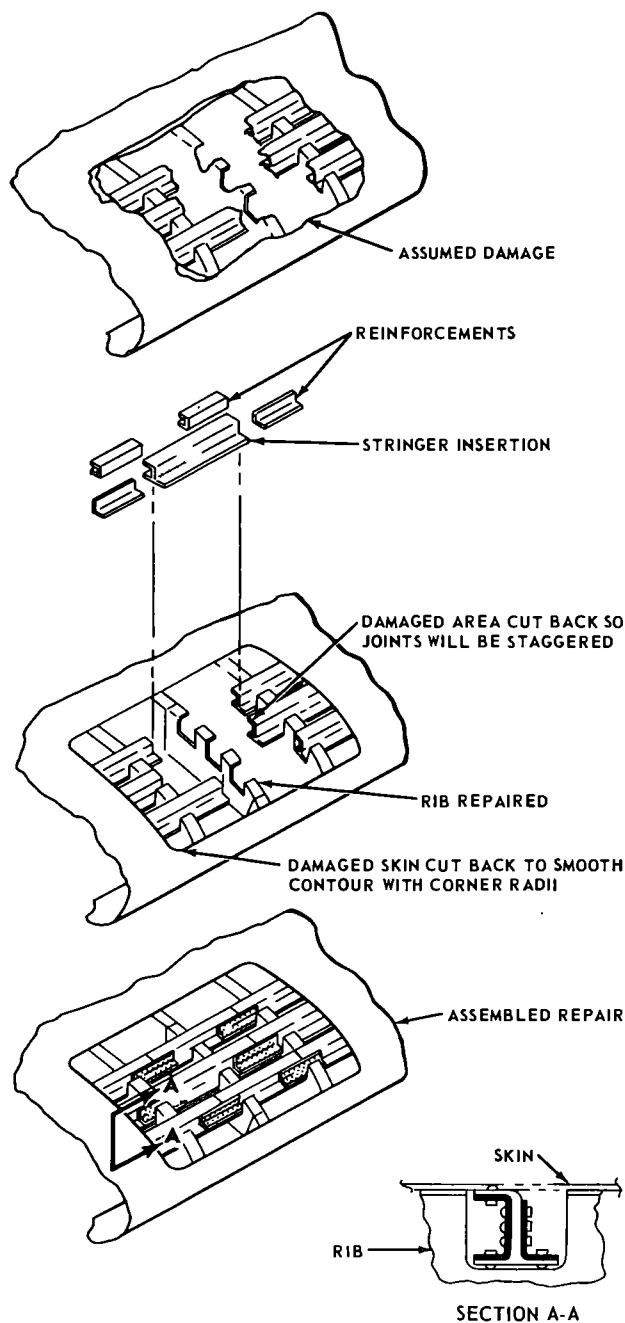


Figure 246. Stringer repair by insertion (damage affecting more than one stringer).

the oval-shaped members of the fuselage which give form to and maintain the shape of the structure. Bulkheads or formers are often called forming rings, body frames, circumferential rings, belt frames, and other similar names. They are designed to carry concentrated stressed loads.

(1) There are various types of bulkheads. The most common type is a curved channel formed from sheet stock with stiffeners added. Others have a web made from sheet stock with extruded angles riveted in place as stiffeners

and flanges. Most of these members are made from aluminum alloy. Corrosion-resistant steel formers are used in areas which are exposed to high temperatures.

(2) Bulkhead damages are classified in the same manner as other damages. Specifications for each type of damage are established by the manufacturer and specific information is given in the applicable manual for the aircraft. Bulkheads are identified with station numbers which are very helpful in locating repair information.

(3) Repairs to these members are generally placed in one of two categories: one-third

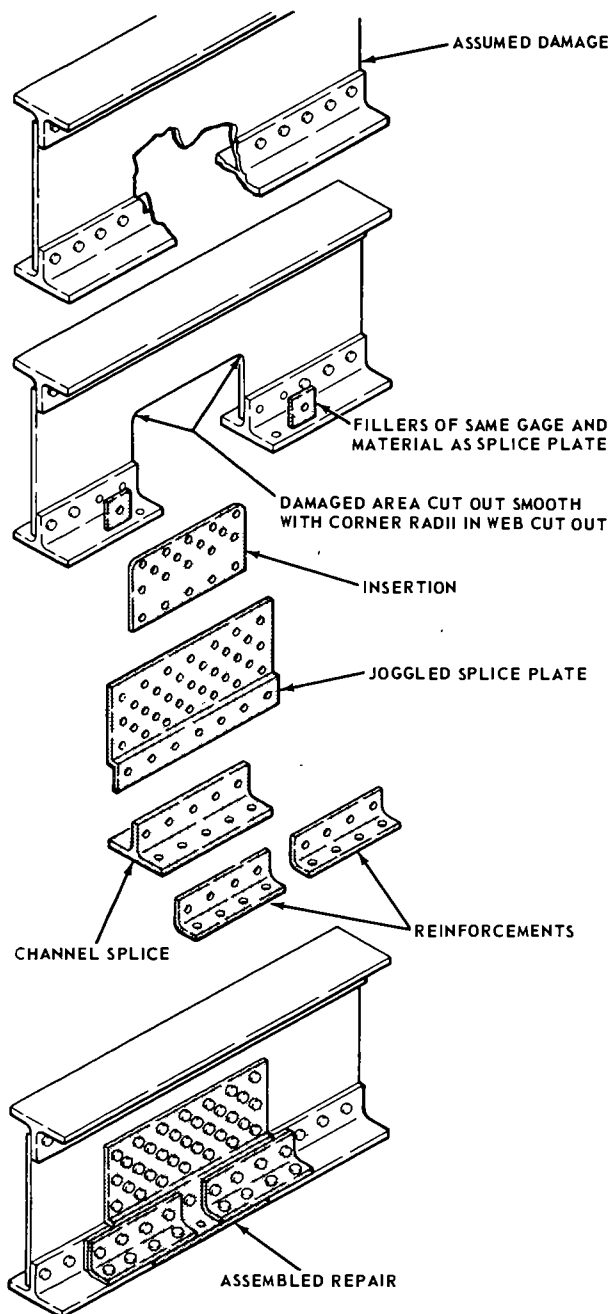


Figure 247. Spar repair by insertion.

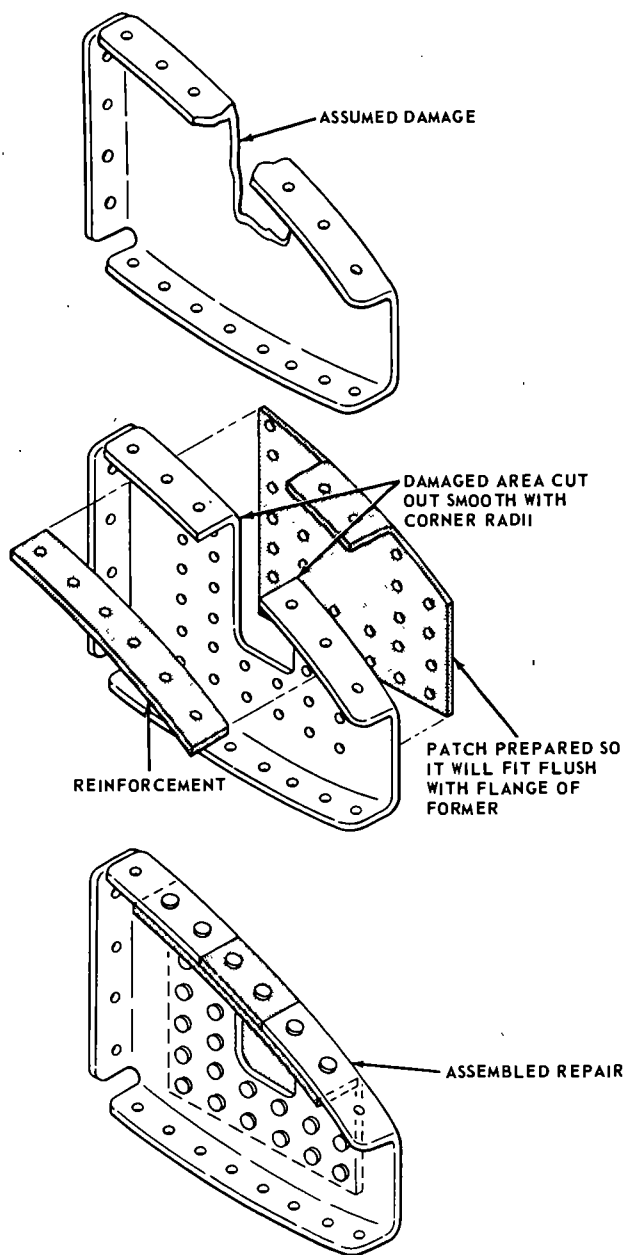


Figure 248. Rib repair by patching.

or less of the cross sectional area damaged, or more than one-third of the cross sectional area damaged. If one-third or less of the cross sectional area has been damaged, a patch plate, reinforcing angle, or both may be used. First, clean out the damage and then use the rivet formula given in paragraph 138h, to determine the number of rivets required in order to establish the size of the patch plate. For the length of the break, use the depth of the cutout area plus the length of the flange.

(4) If more than one-third of the cross sectional area is damaged, remove the entire section and make a splice repair (fig. 250). When removing the damaged section be careful not to

damage the surrounding equipment such as electrical lines, plumbing, instruments, and so forth. Use a hand file, rotary file, snips, or a drill to remove larger damages. To remove a complete section, use a hacksaw, keyhole saw, drill, or snips.

(5) Measure the length of break as shown in figure 250, and determine the number of rivets required by substituting this value in the rivet formula. Use the double shear value of the rivet in the calculations. The result represents the

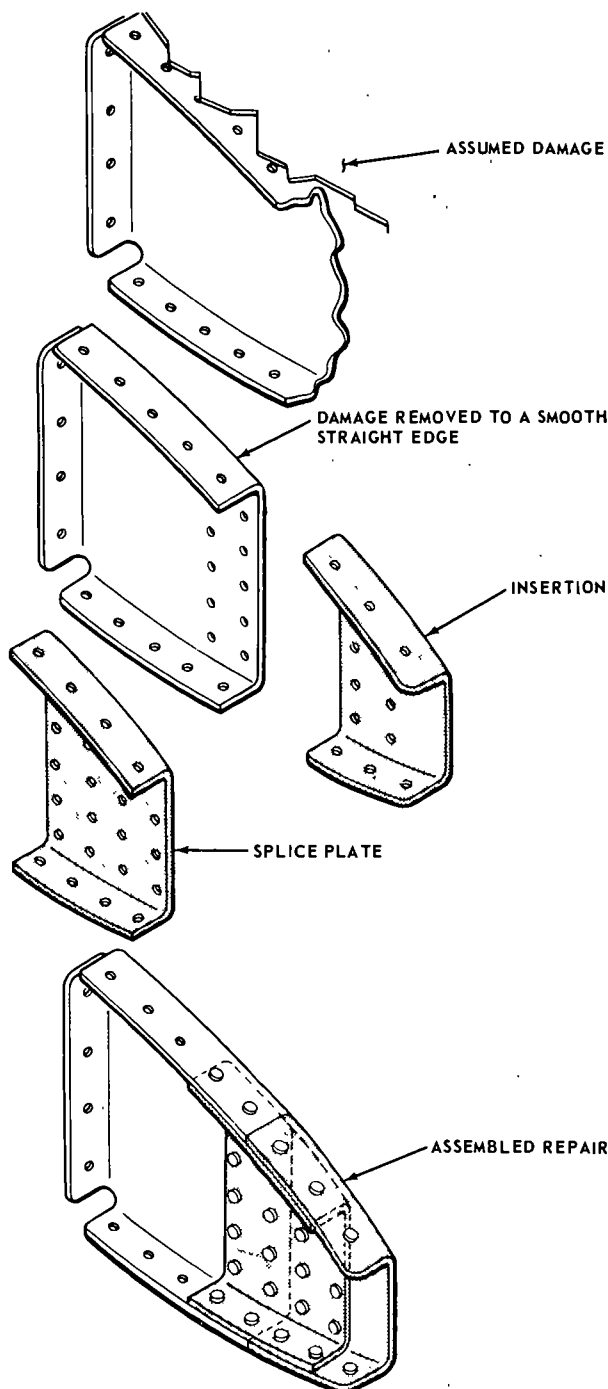


Figure 249. Rib repair by insertion.

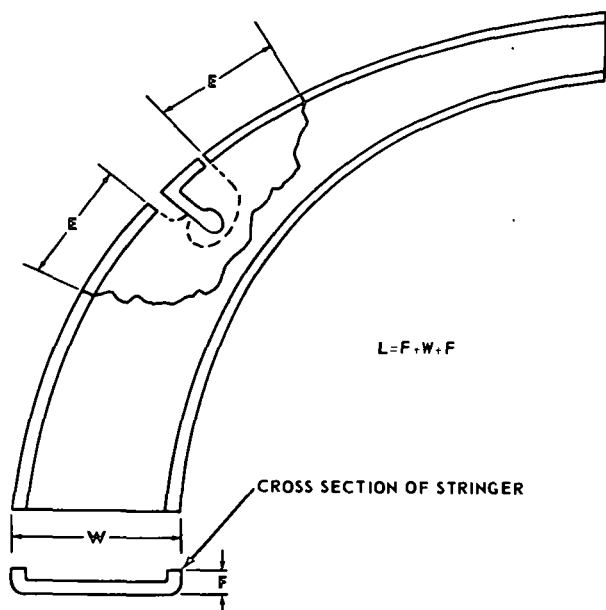


Figure 250. Determining length of break.

number of rivets to be used in each end of the splice plate.

(6) Most repairs to bulkhead are made from flat sheet stock if spare parts are not available. When fabricating the repair from flat sheet, remember that the substitute material must provide cross sectional tensile, compressive, shear, and bearing strength equal to the original material. Never substitute material which is thinner or has a cross sectional area less than the original material. Curved repair parts made from flat sheet must be in the annealed condition before forming, and then must be heat-treated before installation.

f. Leading Edge Repair. The leading edge is the front section of a wing, stabilizer, or other airfoil. The purpose of the leading edge is to streamline the forward section of the wings or control surfaces so that the airflow is effective. The space within the leading edge is sometimes used to store fuel. This space may also house extra equipment such as landing lights, plumbing lines, or thermal anti-icing systems.

(1) The construction of the leading edge section varies with the type of aircraft. Generally, it will consist of capstrips, nose ribs, stringers, and skin. The capstrips are the main length-wise extrusions and serve to stiffen the leading edges and furnish a base for the nose ribs and skin. They also provide a means of fastening the leading edge to the front spar.

(2) The nose ribs are stamped from aluminum alloy sheet. These ribs are U-shaped and may or may not have their web sections stiffened.

Regardless of design, their purpose is to give contour for the leading edge.

(3) Stiffeners are used to stiffen the leading edge and supply a base for fastening the nose skin. When fastening the nose skin, use only flush rivets.

(4) Leading edges constructed with thermal anti-icing systems consist of two layers of skin separated by a thin air space. The inner skin, sometimes corrugated for strength, is perforated to conduct the hot air to the nose skin for anti-icing purposes.

(5) Damages to leading edges are also classified in the same manner as other damages. Damages can be caused by contact with other objects; namely, flying missiles, flak, pebbles, birds in flight, and the like. The major cause of damage is carelessness in maintenance while the aircraft is on the ground.

(6) A damaged leading edge will usually involve several structural parts. Flying-object damage will probably involve the nose skin, nose ribs, stringers, and possibly the capstrip. Damage involving all of these members will necessitate installing an access door in order to make the repair possible. First, the damaged area will have to be removed and repair procedures established. The repair will need insertions and splice pieces. If the damage is serious enough, it may require repair of the capstrip and stringer, a new nose rib, and a skin panel. When repairing a leading edge, use only the procedures prescribed in the applicable manual for this type of repair.

g. Trailing Edge Repair. A trailing edge is the rearmost part of an airfoil, found on the wings, ailerons, rudders, elevators, and stabilizers. It is usually a metal strip which forms the shape of the edge by tying the ends of a rib section together and joining the upper and lower skins. Trailing edges are not structural members, but they are considered to be highly stressed in all cases.

(1) Damage to a trailing edge may be limited to one point or extended over the entire length between two or more rib sections. Besides damage resulting from collision and careless handling, corrosion damage is often present. Trailing edges are particularly subject to corrosion because moisture collects or is trapped in them.

(2) Thoroughly inspect the damaged area before starting repairs, and determine the extent of damage, the type of repair required, and the manner in which the repair should be performed. When making trailing edge repairs, remember that the repaired area must have the same contour and be made of material with the same

composition and temper as the original section. The repair must also be made to retain the design characteristics of the airfoil.

(3) Damage occurring in the trailing edge section between the ribs can be repaired as shown in figure 251. Cut out the damaged area and make a filler of either hardwood, fiber, or cast aluminum alloy to fit snugly inside the trailing edge. Then make an insert piece of the same material as the damaged section and shape it to match the trailing edge. Assemble the pieces as

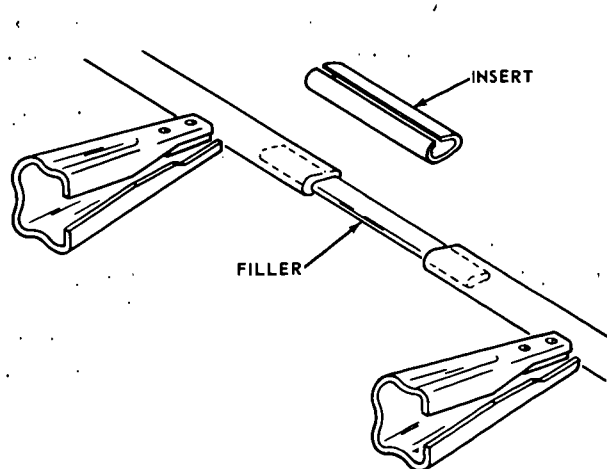


Figure 251. Trailing edge repair between ribs.

shown and rivet them into place using countersunk rivets and forming countersunk shop heads to get a smooth contour.

(4) To repair damage occurring at or near a rib, first remove sufficient trailing edge material to allow a complete splice to fall between the ribs. This usually requires two splices joined by an insert piece of similar trailing edge material or of formed sheet stock. The repair procedure is similar to that for damage between ribs. Figure 252 shows this type of repair.

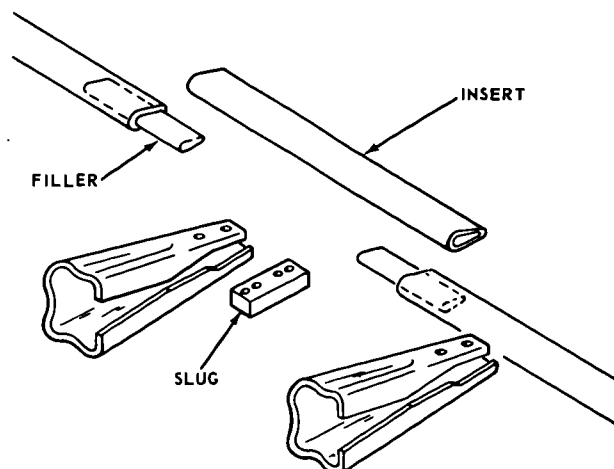


Figure 252. Trailing edge repair near a rib.

Section III. STRUCTURAL SEALING

142. General

a. Various areas of airframe structures are sealed compartments where fuels or air must be confined. These areas contain fuel tanks and also consist of pressurized compartments, such as the pilot's compartment. Because it is impossible to seal these areas completely airtight with a riveted joint alone, a sealing compound or sealant must be used. Sealants are also used to add aerodynamic smoothness to exposed surfaces, such as seams and joints in the wings and fuselage.

b. Three types of sealers are ordinarily used. Rubber seals are installed at all points where frequent breaking of the seal is necessary, such as canopies and access doors. Sealing compounds are used at points where the seal is seldom broken except for structural maintenance or part replacement, as with riveted lap and butt seams. Special seals are required for passing cables, tubing, mechanical linkages, and wires out of pressurized or sealed areas.

c. Wires and tubing are passed through pressure bulkheads by using bulkhead fittings, such as cannon plugs for wiring, and couplings for

tubing. These fittings are sealed to the bulkhead and the wires and tubes are fastened to them from each side. All seals of moving components, such as flight controls, are subject to wear, and utmost care must be used when they are installed. Also, they must be checked regularly.

143. Determining Sealant Defects

Pressure tightness of an area or section is checked before and after a repair is made. Ground pressurization is accomplished by filling the section with air from an external source through ground pressure test fittings.

a. The following precautionary measures should be taken during the testing procedure outlined in b below. With personnel inside, the area should never be pressurized to a pressure higher than has previously been established during testing with the section empty. No person with a cold or having recently had one, or whose sinuses are impaired in any way, should work in the pressurized section. A qualified operator should be present at the pressurization equipment control panel at all times while the section is being pressurized, and if the cockpit is being

pressurized, all personnel should stand clear of the canopy.

b. With the section pressurized to a given pressure, locate leaks on the outside of the aircraft by applying a soapless bubble fluid to all seams and joints in the suspected area. Air bubbles will locate the general area of leakage. A specific leak is then isolated on the inside of the aircraft by passing the free end of a stethoscope or similar listening device along the seams in the leakage area. The leaks can be detected by the change in sound when the instrument passes over it. After completing the test, remove the soapless bubble fluid from the outside of the aircraft by washing with clear water to prevent corrosion.

c. Pressurization may not always be necessary to determine defectively sealed areas. Sealants should be repaired when the following conditions are present: sealants have peeled away from the structure; seams are exposed through the sealant fillet; fillet or hole filling sealant is exposed through the smooth overcoating; sealant is damaged by the removal and reinstallation of fasteners, access doors, and other sealed parts; and cracks and abrasions exist in the sealant.

144. Sealant Repair

a. All surfaces which are to be sealed must be cleaned to insure maximum adhesion between the sealant and the surface. Loose foreign material can be removed by using a vacuum cleaner on the affected area. Scrape all the old sealant from the repair area with a sharp plastic, phenolic, or hardwood block to prevent scratches, and apply a stripper and a cleaner. Turco 2822 can be used as a stripper, and aliphatic naphtha, ethyl acetate, or lacquer thinner can be used as a cleaner. The aliphatic naphtha can be satisfactorily used by dipping a clean rag or brush into the naphtha and then scrubbing the surface.

b. The cleaner should not be allowed to dry on a metal surface, but should be wiped dry with clean rags. Do not remove the cleaner with soiled rags, as the metal surface must be free of all dirt, grease, powder, and so forth. The surface can be checked for cleanliness by pouring water over it after it has been wiped dry of the cleanser. If the surface is not free of oily film, the water will separate into small droplets.

c. Extreme care should be exercised to protect any undamaged sealant and acrylic plastics from the stripper compound. If artificial lighting is used when the repair is made, be sure the light is explosive-proof. Wear clothing which affords adequate protection from the stripper and cleaner so that these chemicals cannot contact the skin. Wear goggles to protect the eyes.

145. Types of Sealing Compounds

Three of the most commonly used sealing compounds are EC-750, manufactured by the Minnesota Mining and Manufacturing Co.; RL-1973, manufactured by W. P. Fuller and Co.; and 2H-24E, which is a putty manufactured by Press-tite Engineering Co. Impregnated zinc chromate tape is often used with sealing compounds. Two of the most frequently used types of tape are UL-10156, manufactured by the Pittsburgh Plate Glass Co., and UX-20-11, manufactured by the Sherwin-Williams Co.

146. Application of Sealants

a. It may be necessary to replace rubber seals periodically to insure tight canopy or door closure. Seal of this type should be replaced any time there is any degree of damage. Such a seal is not repairable, as it must be continuous around the opening.

b. To remove the old seal, remove all the seal retainers from the frame and then pull off the old seal. Use aliphatic naphtha and clean rags to clean the frame on which the new seal is to be cemented. Cleaning should be done immediately before sealer installation. Then, using a clean paintbrush, apply an even coat of rubber cement (EC-524) upon the metal parts and the seal surfaces which are to be joined.

c. Allow the rubber cement to dry until it becomes quite sticky. Then join the seal to the metal by pressing it firmly along all contact points. Install the seal retainers and allow the seal to set for 24 hours before using.

d. Toluene may be used for cleaning the brushes and other equipment used in applying the rubber cement. If the rubber cement needs thinning, use aliphatic naphtha.

e. When sealing is done on pressurized sections, the seal must be able to withstand a certain amount of pressure. Therefore, repair of any damage to the seals in the compartment or section must be made with this thought in mind: can it withstand the pressures required? Pressure sealing must be performed on the pressurized side of the surface being sealed. Make sure that all areas are sealed before further assembly operations are completed which would make the area inaccessible.

f. Sealing compounds should be applied only when the contacting surfaces are perfectly clean. The compound should be spread from the tube by using a continuous forward movement to the pressure side of the joint. It is advisable to start the spreading of the compound 3 inches ahead of the repair area and continue 3 inches past it. If the compound is in bulk form, apply it with a pressure gun. Two coats, or layers, of

compound are often required. If this is necessary, let the first application cure before the second is applied. Allow the compound to cure until it becomes tough and rubbery before joining the surfaces.

g. Curing time varies with temperature. High temperatures shorten the curing time and low temperatures lengthen it. Artificial heat may be used to speed up curing, but care must be used to avoid causing injury to the sealant with too high a temperature. Warm circulating air, not over 120°F. (49°C.), or infrared lamps placed 18 inches or more from the sealants, are satisfactory heat sources. If infrared lamps are used, adequate ventilation must be provided to carry away the evaporated solvents.

h. Sealing compounds are most generally used on seams and joints, but they may also be used to fill holes and gaps up to 1/16 inch in width.

i. Impregnated zinc chromate tape is sometimes used between seams and joints. Sealing tape is also used as a backing strip over holes and gaps which are 1/16 to 3/16 inch in width. The tape is applied over the opening on the pressure side, and a fillet of sealing compound is applied over the tape. Holes and gaps over 3/16 inch in width are usually plugged with wood,

metal caps, or metal plugs on the pressure side of the area, and then impregnated tape and sealing compound are applied over the repair.

j. Be sure that all forming, fitting, and drilling has been completed before applying the tape. With the repair surface area clean, unroll the tape with the white cloth innerleaf away from the metal surface. Leave the innerleaf on the tape until just before the parts are assembled. There must be no wrinkles in the tape, and the parts must be joined together with the least amount of sideway motion.

k. The application of the putty sealant is similar to that of sealing compounds. A spatula or sharp-pointed plastic, phenolic, or hardwood block is sometimes used to force and pack the putty into the gaps or seams. Clean the gap or hole by first blowing it with compressed air before applying the putty to the pressure side.

l. Rivets, bolts, and screws do not always seal properly when used in these critical areas or sections. When pressure leaks occur around these fasteners, they should be removed and replaced. The holes should be filled with sealing compound and new fasteners installed immediately. Remove excess sealant as soon as possible to avoid the difficulty encountered after it becomes cured.

Section IV. REPAIR OF FUEL TANKS

147. General

Many of the principles of sealing discussed in paragraphs 150 through 154, are also applicable to fuel tank repair; however, this section will deal mostly with the specific details of fuel tank repair.

a. Fuel tank repairs are generally of two types, structural or sealing. Structural repairs also require the use of sealing materials.

b. Aircraft fuel and oil tanks are placed into two categories, integral tanks and removable tanks. Integral tanks are actually a part of the aircraft structure, being located in the wings and fuselage. These tanks have no lining, so the fuel rests directly against the skin and members of the wings or fuselage. With this type of tank, it is of the utmost importance that all seams and rivets be completely covered with a good coating of sealant, usually the Buna rubber type. In later model aircraft, the wing and fuselage tanks have a bladder or self-sealing type of fuel cell inside the metal covering.

c. Removable tanks include the old metal types, bladder and self-sealing cells, and droppable tanks. The repair of self-sealing cells does not fall within the job description of the airframe repairman, but he is responsible for the repair of the metal enclosures. Droppable tanks are

sometimes repaired, however, in combat areas (after the fuel is exhausted), and in emergency situations, these tanks are usually dropped and are seldom available for repair. The drop tank has no lining and is constructed according to semi-monocoque design.

d. Metal fuel and oil tanks are made from 1100, 3003, and 5052 aluminum. These metals can be successfully welded, and it is recommended that welds be made to insure leakproof tightness. It is the airframe repairman's job to cut out damaged areas, prepare repair materials, and get the repair job ready for the welder. In places where rivets are used, sealing compound is applied at the edges of the patch and at rivet locations. Self-sealing cells must be removed to be repaired. The airframe repairman will then have easy access to damaged skin and structural members in that area.

e. The effectiveness of tank repairs will depend largely on the correct analysis of the damage and the use of correct repair methods. The general requirements for tank repairs include fuel tightness, correct contour, minimum additional weight, restoration of original strength, welds instead of rivets where possible, use of proper sealants, and safety precautions being observed at all times.

148. Safety Precautions

a. Care must be exercised when inspecting and repairing metal fuel tanks. When an opening is made in a fuel tank, air rushes in and the resulting mixture could be highly explosive. The possibility of fire and explosion should never be overlooked. Another hazard is the possibility of inhaling poisonous gases. A third danger is lead poisoning should lead residue come in contact with the skin.

b. The following safety precautions should always be observed when making repairs to metal fuel tanks.

(1) The fuel tank will be defueled, inerted, and purged.

(2) Steam lines, used in cleaning, should be grounded at the discharge end of the line to prevent static discharge.

(3) Observe all bonding and grounding rules for both the fuel tank and the aircraft.

(4) Thoroughly clean the fuel tank and expel all combustible gases.

(5) An explosimeter will be used to determine the concentration of fuel vapors in the tank.

(6) All lights used near tank repairs will be explosive-proof.

(7) Tools will be of the nonsparking type; all power tools will be air-driven.

(8) A respirator will be worn by all personnel entering a fuel tank.

(9) All clothing worn by the repairman will be of cotton to prevent buildup of static electricity.

(10) Anyone entering a fuel tank will wear protective footwear, such as cotton boot socks over the shoes, or preferably, rubber boots.

(11) Rubber gloves will be worn, and they should never be touched with the bare hands after use until they have been thoroughly washed.

(12) Open flames for heating or welding will be used only after complete clearance of fuel and fuel vapors from the tank and surrounding areas.

149. Inspection (Integral-Type Fuel Tank)

a. The boundary of an integral fuel tank is a network of interlocking seams. Leaking fuel will travel along a seam, or from one seam to another, and may not be apparent on the external surface in the same vicinity as the actual leak. A leak should always be pin-pointed and never just located in a general area. It is not sufficient to cover an entire area of several feet with sealant and hope to get the leak stopped. This may only start the flow in another direction and, even though it appears to have been corrected, the leak may appear later at another point.

b. The general types of fuel leaks may be classified and identified as follows:

(1) *Stain*. A dry discolored area, 1/2 to 3/4 inch in diameter.

(2) *Seep-wet*. A discolored area up to 1 1/2 inches in diameter.

(3) *Heavy seep-wet*. A discolored area up to 4 inches in diameter.

(4) *Running leak*. An area larger than heavy seep-wet with dripping or continuous flow.

c. The best method of finding leaks is by applying a soapless bubble compound on the outside of the tank and then pressurizing it. Air bubbles will appear at the leak points.

150. Cleaning (Integral-Type Fuel Tanks)

a. If a fuel tank is to be repaired, first defuel it and remove the gases with steam or carbon dioxide (CO₂). This process is called *inerting*. If steam is used, introduce it into the tank from the top and allow the gases to escape from the bottom. A tank should be steam-cleaned for about 3 hours. When using CO₂, allow the fumes to escape out of the top, as CO₂ is heavier than air. Do not breathe large amounts of CO₂, since it does not contain oxygen for breathing.

b. It may be necessary to remove the old sealing compound when making a fuel tank repair; if so, use a plastic, phenolic, or hardwood scraper, which also prevents scratching the metal. The area must be clean to insure good adhesion of the sealant to the metal. Use cheesecloth and one of the previously mentioned cleaners. Observe the same cleaning precautions as outlined when preparing a pressurized section for sealing. In addition, dry the area for about 10 minutes, using an air hose containing no water or oil. All cleaning solvent must be evaporated.

151. Sealing (Integral-Type Fuel Tank)

a. A synthetic rubber compound is used for sealing metal tanks. It is mixed with an accelerator to get the desired consistency for use, and adheres well to aluminum and rubber if properly prepared. After the sealant is applied, it is overcoated with a substance such as Buna N. The completed seal has satisfactory adhesive, fuel-resistant, and low-temperature flexibility qualities.

b. Most fuel leakage, except from tank punctures, is caused by improper preparation and application of the sealant. Some general rules for the use of the sealant are as follows:

(1) Do not guess; always determine the exact source of the leak and apply sealant in the proper place.

(2) Clean the area thoroughly to permit maximum adhesion.

(3) Do not spread the sealant too thin.

(4) If screws are used for fastening, avoid using ones that are too long. Screws which pass through the sealant will allow fuel leakage down the threads.

(5) Use plenty of sealant in areas under stringers and fittings, and replace and seal all damaged rivets.

(6) Mix sealant exactly as specified in the applicable manual, and pressurize the fuel tank for testing.

Section V. SANDWICH CONSTRUCTION

153. Definition and Purpose

a. Sandwich construction may be defined as a laminar construction which consists of a combination of alternating, dissimilar materials. These materials are assembled and intimately fixed in relation to each other so that the properties of each can be used to attain specific structural advantages for the whole assembly.

b. Sandwich construction in flat or curved panels is usually used on aircraft. The panels consist of three or more laminations of widely dissimilar materials which are considered similar in nature when bonded together. The function of the center layer, or core, is to hold the other layers, or facings, apart, and to provide sufficient stiffness to prevent the facings from becoming elastically unstable when put under high stress loads.

c. The design of the sandwich panel is governed by the use for which it is intended, as the panel itself is a structure. Such panels are especially useful in the manufacture and repair of aircraft because they utilize lightweight core materials in combination with facings to obtain strong rigid panels of minimum weight.

d. Experimental applications for the use of sandwich construction in the manufacture and repair of aircraft are being made in the production of bulkheads, control surfaces, fuselage, wings, empennage skins, radomes, and shear webs.

154. Core Materials

Core materials are very important in the manufacture of sandwich constructed parts because they supply much of the strength for which the part is designed. The core materials must be able to transmit stress loads and, at the same time, conform to definite weight limitations. The stresses to which the core is subjected will vary with the strength requirements of the sandwich over a wide range, depending upon the application; therefore, the allowable weight of the core must necessarily be adjusted to its use. Core materials

152. Curing (Integral-Type Fuel Tank)

After the sealant is applied and before the overcoating is put on, it is subjected to a process called curing. Curing consists of circulating air, at room temperature, through the tank for about 30 minutes; afterward, the air is circulated over periods of time and temperature ranges as recommended in the applicable manual. Curing procedures must be performed again after the application of the overcoating.

for sandwich construction are of four general types, natural core materials, foamed or cellular materials, foamed-in-place core materials, and honeycomb core materials.

a. *Natural Core Materials.* The natural core materials are confined to wood. The principal wood used in balsa, with mahogany, spruce, and poplar being employed as inserts and edge banding.

(1) If care is exercised in the selection of balsa, excellent properties for core material application are available. Those directly associated with the manufacture of sandwich construction have found that properly selected balsa has desirable characteristics of lightweight, uniform high compressive and tensile strength, and elasticity; retention of strength through wide ranges of temperature; ease of machining; and good bonding characteristics.

(2) The characteristics will vary because of growth conditions. That is why proper selection, inspection, and grading are necessary. It is required that defects such as core decay, seasoning defects, pith, large knots, and excessive slope in grain be eliminated. The trained individual can readily detect any of these defects.

(3) High strength inserts are usually needed for sandwich panels at points of attachment and along exposed edges. End grain mahogany has desirable characteristics for use under these conditions. One of these traits is the specific gravity of end grain mahogany, which is determined by weight and measurement of planed boards. When taken on boards having 8- to 12-percent moisture content, the specific gravity is normally 0.04 to 0.56. Stated in simpler terms, this means that the weight of planed mahogany boards having a moisture content of 8- to 12-percent is normally 25 to 35 pounds per cubic foot. Some mahogany has defects which make it undesirable for use as core materials, such as decay, seasoning defects, loose knots, and com-

pression failures. These defects must be detected and the boards eliminated.

(4) Spruce is sometimes used as a substitute for mahogany as a high-strength insert. The poor machining properties of spruce, and the difficulty encountered in bonding end grain surfaces, are responsible for its limited use as a core material.

b. Foamed or Cellular Materials. Since some disadvantages, such as variable density and high moisture absorption, are encountered when using natural core materials, attempts have been made to develop synthetic core materials having satisfactory strength properties. The specific gravity of otherwise suitable base materials is too high when used as a solid mass. Therefore, materials such as these must be foamed, expanded, or processed by some other method that will reduce the apparent density to a suitable range. The processes used can be controlled, thus making it possible to predict within relatively narrow limits, the physical properties of the resulting core material. Cellulose acetate, expanded rubber, and polystyrene are examples of foamed or cellular core materials. These materials are available in varying specific gravity ranges.

c. Foamed-In-Place Core Materials. Certain types of radomes made of sandwich construction require the use of core materials that will provide desirable characteristics of radiation transmission. The thickness of the structure must be tapered, and close control of facing, core, and sandwich thickness must be maintained. To obtain these desirable characteristics, efforts have been directed toward the development of a core material that can be foamed-in-place between premolded, laminated, glass fabric base plastic facings, and will adhere to these facings. A core material such as this is not as strong as glass fabric honeycomb. Its advantages are uniformity of cell structure, elimination of core joints, a thinner and more uniform bonding layer between facings and core, accurately premolded void-free inner and outer skins, and greater flexibility in manufacture. Uniform density foams, with 3- to 30-pound density per cubic foot, have been produced by using these materials. Materials having a density of 10 to 12 pounds per cubic foot are most commonly used. These alkyd-diisocyanate foams have also been used for stabilizing hollow steel propeller blades and control surfaces made from aluminum alloy.

d. Honeycomb Core Materials. The use of honeycomb type core materials has increased during the past few years. It is made by fabricating sheet material in such a manner that a cross section of the structure resembles a bee's honey-

comb. The desired properties and densities are produced by varying the type of sheet material, its thickness, and the cell size. Honeycomb core materials with a specific gravity range of 0.05 to 0.16 (3 to 10 pounds per cubic foot) are available. Resin-impregnated glass cloth, resin-impregnated cotton cloth, and aluminum foil are being used extensively in the manufacture of aircraft sandwich materials. Resin-impregnated paper shows definite promise as a honeycomb core material. Experiments are being conducted to determine the advisability of using asbestos, glass fiber mat, and magnesium foil in honeycomb structures. The glass fiber mats are less desirable than the others because they cannot be corrugated with any degree of success. Honeycomb as a core material has proven to be versatile and practical because of the wide variations and combinations of sheet type, fiber direction, type of resin, cell size available for use, and the exceedingly broad specific gravity range.

(1) *Glass cloth honeycomb material.* Glass cloth honeycomb material is made by impregnating glass cloth with a polyester or phenolic resin. Honeycomb structure made of this material is available in 3/16-, 1/4-, and 3/8-inch hexagonal cell sizes. The normal specific gravities available are 0.08, 0.13, and 0.15 (5, 8, and 9 pounds per cubic foot); however, the specific gravity of each cell size can be varied over a wide range.

(2) *Cotton cloth honeycomb material.* Cotton cloth honeycomb core material with hexagonal cells approximately 7/16 inch in diameter, and with densities of 0.06 and 0.12, are available for use in sandwich structures. The weight of the material with a density of 0.06 is 4 pounds per cubic foot, while the weight of the 0.12 density material is 8 pounds per cubic foot. It does not matter if the density is 0.06 or 0.12 so far as the treatment of the cloth is concerned, because a phenolic-type resin is used to give the necessary compressive strength and resistance to moisture. The chief use of cotton cloth honeycomb materials is in the manufacture of sandwich partitions, bulkheads, and baggage rack floor panels. It is unsuited for radar because of its poor dielectric and moisture absorption properties.

(3) *Aluminum honeycomb material.* Aluminum honeycomb is made by corrugating sheets of aluminum foil and cementing them together to form the honeycomb structure. The density of the structure can be closely controlled by varying the foil thickness and the cell sizes. Cell sizes available are 1/4, 3/8, and 1/2 inch across. Perforations permit the escape of vola-

tile gases and the passage of air through the core structure. Limited double curvature forming is possible when the lighter foil gages are used.

155. Facing Materials

The facing material is very important to the effectiveness of aircraft parts made of sandwich construction, as facings carry the major loads applied to the structure. The characteristics of the facings must include the necessary stiffness, stability, configuration, and strength for the part. Facings sometimes have other uses, such as providing aerodynamic smoothness, rough nonskid surfaces, and tough, wear-resistant floor coverings. Facings are classified into two types, depending on the materials used. One type is that of the rigid, strong materials, such as metal, fiber-reinforced plastic, or plywood sheets that are bonded to the core. The other type facings are fabric, or mat materials, that are wet-laminated in place, with the resin giving the facing acceptable rigidity and securing the bond to the core. The advantages and limitations of each facing material must be considered, and care must be exercised in choosing the composition that is comparable to the requirements of the sandwich, fabrication, assembly, and maintenance details. Aluminum alloys with thickness of 0.12 to 0.064 inch are commonly used as facings for structural and nonstructural sandwich application. The alloys of aluminum best suited for sandwich structures are 7075S-T6, 2024S-T3, and 2014S-T6. Sheets coated with corrosion-resistant aluminum (clad) are preferred because they have maximum corrosion resistance during processing and when exposed to extreme weather conditions. Special care must be exercised to avoid wrinkles, dents, and half moons when aluminum sheets are being handled. Such defects cannot be completely removed during processing, and could cause premature failure of the panel. The use of steel in aircraft sandwich construction is very limited. The best example is its use in sandwich propeller blades, and such usage will probably increase as the power output of engines increases. The use of sandwich structure makes it possible to increase the size of the propeller and, at the same time, avoid the problem of too much weight. The chief disadvantages of using steel for sandwich applications are its poor corrosion resistance and high weight.

a. Magnesium Alloys. Magnesium alloy sheets were seldom used in the past, and then mostly in experimental work. The probability of using magnesium more extensively in the future is very

likely because of its low density and stiffness characteristics.

b. Resin-Impregnated Glass Cloth. Resin-impregnated glass cloth has acceptable properties for use as facing on structural sandwiches if the fabrication processes are properly performed. Because of its excellent dielectric properties, it is being used almost universally for sandwich-constructed radomes. A wide range of directional strength properties are possible, as the glass cloth is available in a variety of weaves which make it practicable to fit the fiber directions in the facing.

c. Glass Fiber Mats. Glass fiber mats are used sparingly in aircraft sandwich construction. The main reasons for not using this type material are its nonuniformity in thickness, resin content, and its low strength when compared to glass cloth.

d. Plywood Facings. Plywood facings were first used successfully in the British Mosquito Bomber. This marked the first major structural application of sandwich construction in the aircraft industry. Plywood facings are seldom used in the manufacture of major structural components of aircraft in the United States. Their use is confined primarily to the fabrication of lightly stressed bulkheads, partitions, and baggage racks.

156. Adhesives and Resins

Conventional synthetic-resin adhesives can be used in the fabrication of plywood-faced sandwich parts. The type of synthetic-resin adhesive to use for a particular job will depend upon the durability requirements, the effect of adhesive solvents on the core material, and the limits of bonding conditions, such as assembly time, pressure, and curing conditions. Recently, resin adhesives were developed that are satisfactory for bonding metal-to-metal and metal-to-wood. Most of these adhesives are very complex, and their chemical structure is not as simple nor as well known as that of the woodworking adhesives. As a result, it is necessary to use some system that will make the selection of the proper adhesive easier. The system of classification that was adopted is that of curing temperature and techniques by which the adhesives are used. The three general types of adhesives for bonding are classified as high-temperature setting adhesives; combination or two-step adhesives; and room temperature setting adhesives.

a. High-Temperature Setting Adhesives. The high-temperature setting adhesives require that a joint be cured under pressure at temperatures of 250° to 350°F. (121° to 177°C.). Some of these adhesives are supplied in dual parts; a liq-

uid and a film tape, or as two liquids. These dual-adhesive systems are used to produce better adhesive flow characteristics during curing.

b. Combination or Two-Step Adhesives. Combination or two-step process adhesives are the same type as those used for direct bonding to metals, known as primers or primary adhesives, and are applied on the metal surface only. The primary adhesive is cured in an oven or on the platens of a hot press at temperatures of 300° to 335°F. (149° to 168°C.). Then the final bonding of the primed metal to the core material is made under pressure at room temperature, or slightly higher, by using a secondary adhesive.

c. Room Temperature Setting Adhesives. Room temperature setting adhesives are available, but thus far have not produced a bond comparable in strength and durability to that obtained by direct high-temperature setting or the two-step methods.

(1) The method of storage and mixing adhesives varies with the manufacturer. Some manufacturers recommend the storage of adhesives at room temperatures, while others contend that storage should be at temperatures of 35° to 70°F. (2° to 21°C.). Most manufacturers recommend that the adhesive be stored in containers with tight covers to prevent the loss of solvents and contamination by dirt and moisture. The storage life of adhesives, maintained at the temperature mentioned above, will vary from 4 months to several years.

(2) Many of the adhesives are sensitive to the presence of moisture, making additional precautions necessary to prevent contamination from condensed atmospheric moisture. When a supply of adhesive is received, the contents should be thoroughly mixed, and then removed to smaller containers and placed in storage at

35° to 70°F. (2° to 21°C.). Be sure the containers are completely filled so moisture-laden air will not be entrapped when the covers are installed. Adhesives should be removed from cold storage and allowed to warm to room temperature before they are used. Check that the covers are on tight to prevent condensation of moisture during the warmup period. Never return a partially filled can of especially sensitive adhesive to cold storage.

(3) The ingredients of some adhesives tend to separate during storage. Manufacturers of these adhesives recommend that they be thoroughly agitated in the container at least once every 2 weeks during storage, and thoroughly mixed just prior to using. If, after mixing, an adhesive is gelled, or heterogenous, it should not be used unless some method of breaking the gel is recommended by the manufacturer.

(4) Most metal bonding adhesives available are supplied as one-part adhesives and only require thorough stirring before being used. A few are supplied as two-resin ingredients to be applied successively to the surfaces being bonded. The manufacturer's instructions should be closely followed in the use of these adhesives.

(5) The viscosity of the adhesive as received is sometimes too great for proper spreading by the method of application being used. When this condition is encountered, the adhesive should be thinned in accordance with the manufacturer's recommendations.

(6) The adhesives used in sandwich construction can be applied to the faying surfaces by any convenient means that will give a smooth, uniform spread of the adhesive. Methods such as a brush, hand roller, conventional roll glue spreader, gear-type applicator, spray gun, and in some instances dipping, have been used.

Section VI. REPAIR OF SANDWICH CONSTRUCTION

157. General

a. Repair procedures for damaged honeycomb structures will vary from one manufacturer to another; however, the overall methods and operations are similar. Figure 253 shows damage to a honeycomb skin. This particular illustration shows a bullet hole through both facings and the core material of both wing surfaces.

b. Figure 254 shows two different methods of cleaning out the damage and the typical maximum limits.

c. Detail (A) of figure 254 shows the distance from the edge of the small circular cutout to the edge of the sandwich structure must be at least 3 1/2 inches. Detail (B) gives the maximum permissible limits of the repair. The maximum

width of a repair to the outer facing of the upper surface wing skin is 12 inches. The inner facing should be cut back 2 inches, on each side, beyond the edge of the cutout for the outer facing. The diameter of the cutout for the plug patch on the inner facing of the lower skin should not exceed 3 inches, and the diameter of the cutout for the outer facing plug repair should not exceed 1 inch.

d. Details (C) and (D) give the type of material from which the doubler should be made, the type of bolts to use, the proper spacing for the bolts and the material to use for the filler. The doubler should be made of 7075ST aluminum alloy, 0.250 inch thick, and the ply should be made of 7075ST aluminum alloy, the same

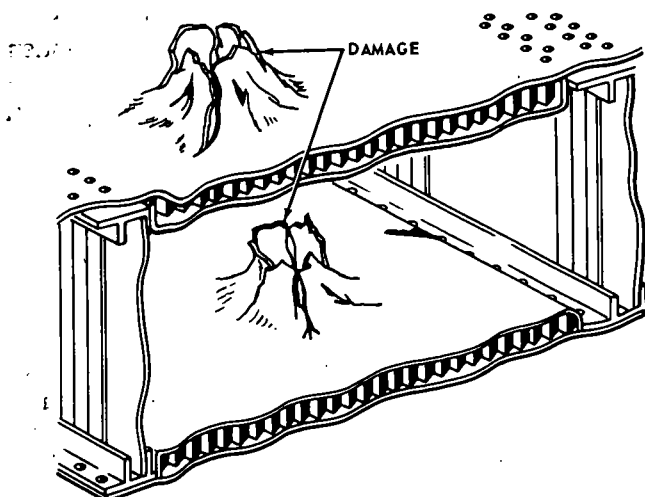


Figure 253. Damaged honeycomb skin.

thickness as the outer facing of the lower wing skin.

e. Detail (E) shows the application of a typical insert and splice plates for the upper surface wing skin. The application of the filleting compound for the plug-type repair is also shown. Detail (F) shows the application of tape over the wood filler.

f. Detail (G) shows the finished repair after all sealing has been completed. Detail (H) shows a cross section of the completed repair.

158. Bonded Stiffeners

In some aircraft, magnesium stiffeners are bonded to magnesium skin in the trailing edge wing panels. The cleaning, priming, precuring of parts, positioning, and final cure of the bond are very carefully controlled. The instructions in the applicable manual should be followed very closely. The bond is made by the following processes:

a. Each faying surface is coated with EC1290 primer which is precured in an oven.

b. M3C adhesive is applied to the joint in tape form.

c. The bond is cured on a heated platen (table) with pressure of approximately 10 psi applied by a vacuum bag over the top of the part.

159. Repair of Bonded Magnesium Panels

Some aircraft use honeycomb bonded magnesium construction in trailing edges. The repair of these panels must be made with an adhesive which cures at a lower temperature than the rest of the bonds in the panel. To avoid the field problems of heated baths and complicated processes required to clean magnesium, aluminum repair parts are used (fig. 255).

a. The repair structure is cleaned by stripping the zinc chromate primer with methyl-ethyl-ketone and removing old adhesive with Kelite Deseal 2L.

b. Both faying surfaces are primed with EC-1290 primer and precured at 220° to 240°F. (104° to 116°C.) for 35 to 45 minutes with heating blocks.

c. Epon VI is used as the adhesive for repairs. A curing agent (accelerator) is mixed with the Epon, and the adhesive is applied to one surface of the joint. The final bond is cured under a pressure of 4 to 20 psi at 160° to 200°F. (71° to 93°C.) for 45 to 90 minutes.

d. Pressure is applied to the repair parts, and counterpressure is applied to the opposite side of the repair area with jigs. The final bond thickness after cure must be within 0.005 to 0.025 inch.

e. The bond is purely an adhesive joint and in no way involves metallurgy. Epon adhesive was developed by the Shell Research Corporation.

f. The EC1290 primer is used to provide a low modulus layer in the cemented joint to distribute shear stress through the joint. (Modulus of elasticity is the ratio of the unit stress to the unit deformation of a structural material.) This ratio is a constant up to the point where the material is permanently deformed. The formula for determining modulus of elasticity up to the point of permanent deformation is— $\text{Modulus} = \frac{\text{stress}}{\text{strain}}$. The strength of the completed joint is primarily dependent upon the thickness of the joint, adhesion to the surface of the metal, continuity of the glue line, and the time and temperature at which the adhesive was cured.

g. Voids or blisters within the cemented joint can only be determined by cutting through the joint. The strength of the joint is tested by shear and peel tests. The completed bond cannot be inspected other than by destruction of the bonded joint. A visual inspection for the presence and continuity of the adhesive is the only mode of inspection.

160. Repair of Skin Panels

The method of metal bonding and of sandwich construction are similar in most of the aircraft that use them. Recommended procedures of repair, and the adhesives and accelerators used, will vary somewhat from one aircraft to another.

a. Some aircraft manufacturers use aluminum honeycomb core bonded to the skin for control surface trailing edges up to the aft beam. Honey-

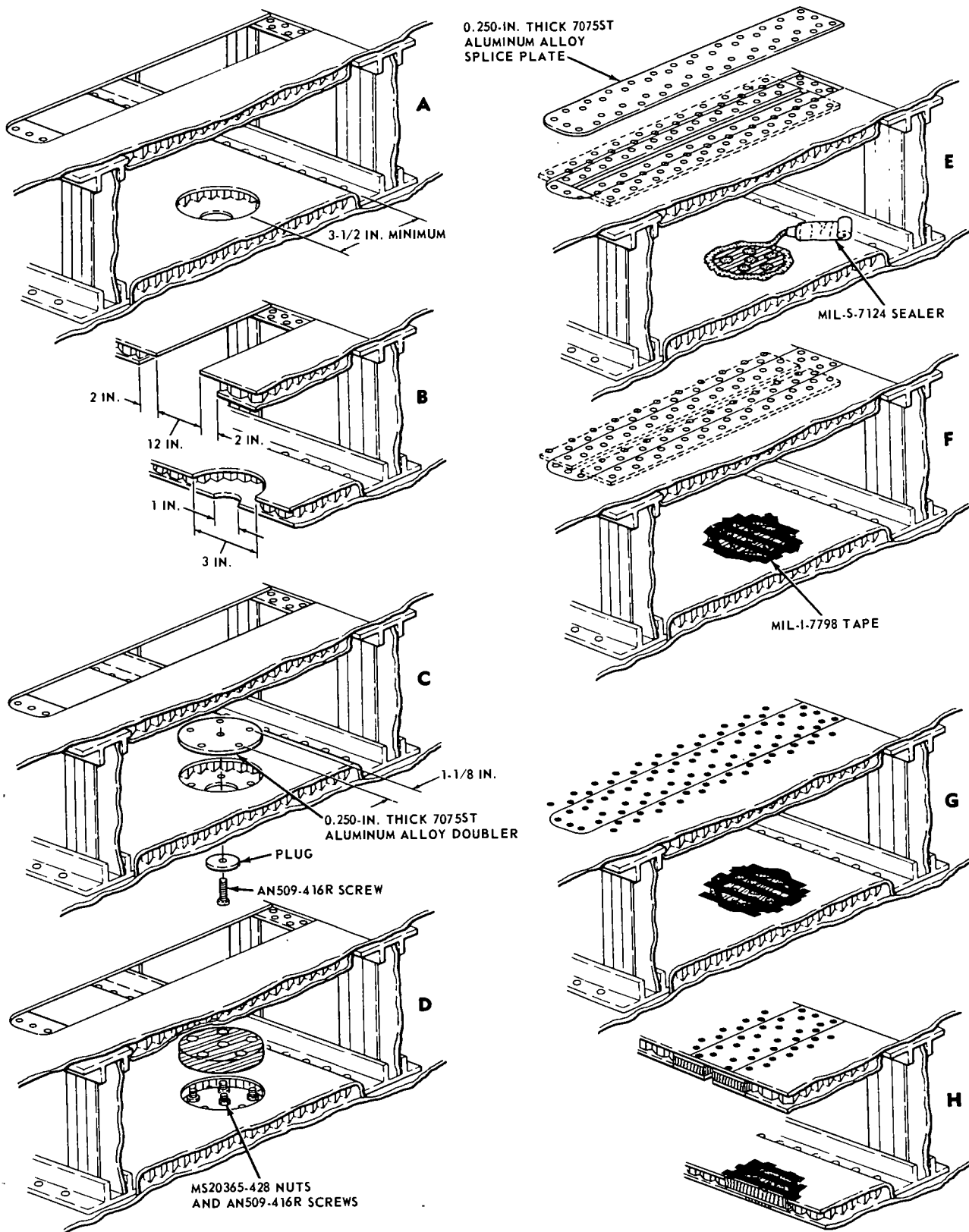


Figure 254. Honeycomb repair.

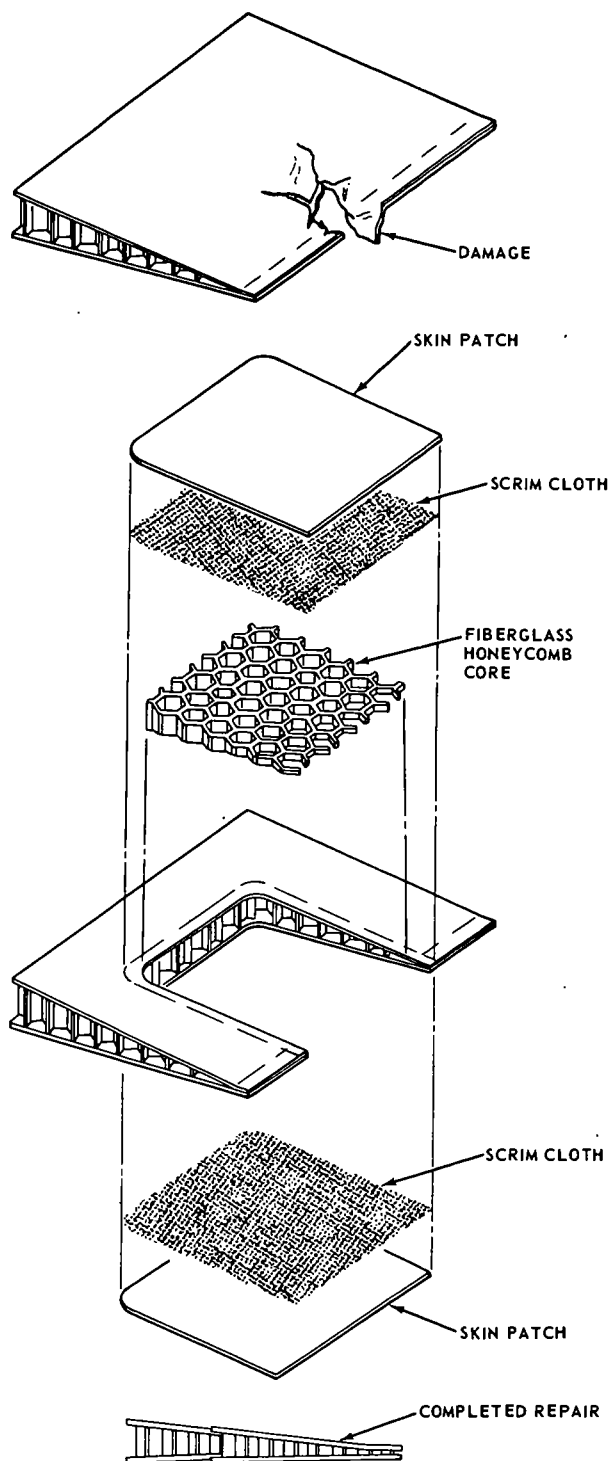


Figure 255. Trailing edge repair.

comb metal construction is also used in the wing-tips.

b. There are three typical honeycomb repairs for damages. Areas requiring such repairs are: the aft portion of the trailing edge of the control surface; the control surfaces forward of the trailing edge which require the repair of both

skins as well as the honeycomb core; and crack or scratch repair.

c. If the aft portion of the trailing edge of a control surface is damaged, proceed as follows:

(1) A micarta filler plug, or one of 2024 or 7075 aluminum alloy, is fabricated to fit the cleaned out area where the damage was removed (fig. 256).

(2) A doubler is fabricated to lap over the repair and up to the joint at the aft beam.

(3) Existing rivets are removed from the beam in the repair area.

(4) Epon VIII is applied to all faying surfaces (mating or adjoining surfaces).

(5) The repair is then bonded and riveted through the existing rivet holes in the beam with bind rivets.

d. A repair to the control surfaces forward of the trailing edge, involving repair of both skins and the honeycomb core, is made as follows:

(1) The damage is removed with a hole saw or router. The diameter of the cutout in the bottom skin will be 1 inch larger than the cutout in the top skin.

(2) The honeycomb is trimmed to the diameter of the larger hole.

(3) A flush patch and doubler are fabricated and installed in the top skin.

(4) The honeycomb core is replaced by an insert of the same material.

(5) All faying surfaces are coated with Epon VIII.

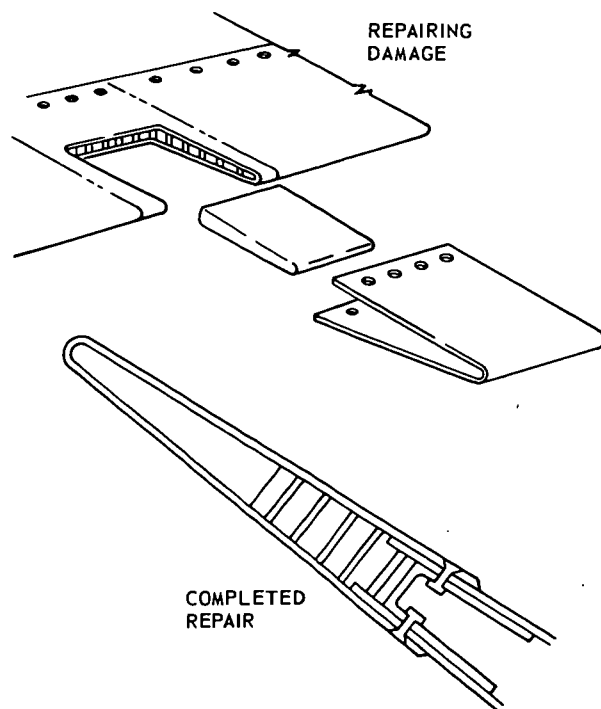


Figure 256. Rudder repair.

(6) A doubler, filler plate, and flush skin patch are fabricated and installed with flush head blind rivets.

(7) Cure of the bond is effected at room temperature over a long period, or at elevated temperatures over a short period.

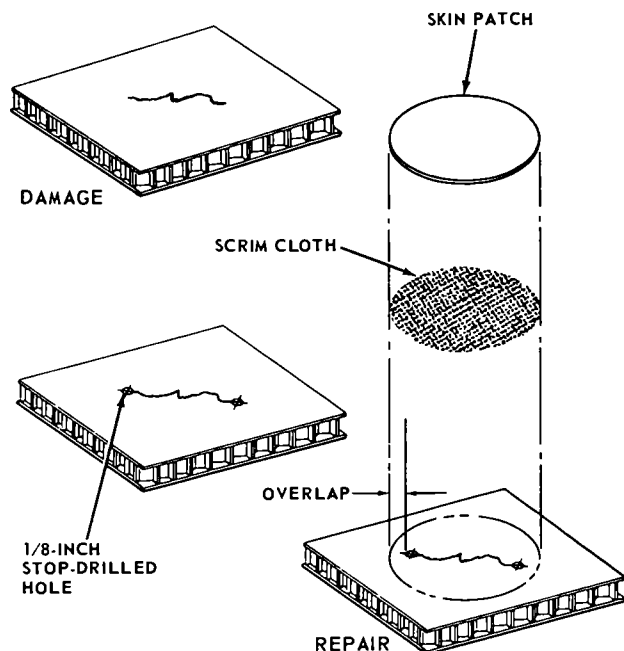


Figure 257. Crack or scratch repair.

e. The third type of repair, crack or scratch repair, is shown in figure 257.

161. Coin Tapping Technique

In some metal bond repairs, the manufacturer suggests using a coin, such as a quarter, and bouncing it lightly on the repaired surface while holding it between the thumb and forefinger, to detect any area where the bond is not complete. A well-bonded spot will have a sharp, metallic ring, while an unbonded spot will have a dull sound. It is also suggested that the skin in unbonded areas may be drilled with several number 0.30 holes, and that the adhesive can then be inserted into the voids with a pressure gun and a new bond be effected in the areas. This may prevent the removal and rebonding of the entire repaired area, especially where the unbonded areas are very small.

162. Cleanliness of Repair Area

One thing on which all manufacturers agree is that the area to be bonded must be absolutely clean. Several cleaning agents are recommended. Determine which one is recommended for the applicable aircraft by reading all the instructions for its use in the applicable manual.

CHAPTER 10

FLIGHT CONTROL SYSTEMS

Section I. FLIGHT CONTROL SURFACES AND SYSTEMS OF AIRPLANES

163. Primary Group Control Surfaces

a. Elevators. The elevators are operated by the control stick or wheel and yoke assembly. Pulling back on the stick or yoke raises the elevators and causes the airplane to climb. Pushing the stick or yoke forward lowers the elevators and causes the airplane to descend or dive. Figure 258 illustrates a typical elevator control system.

b. Rudder. The rudder is operated by the rudder pedals and is used to move the airplane about the vertical axis. Moving the rudder to the right turns the airplane to the right; moving it to the left turns the airplane to the left. The rudder is moved to the right by depressing the right rudder pedal and is moved to the left by depressing the left rudder pedal. Figure 259 illustrates a typical rudder control system.

c. Ailerons. The ailerons are operated by a lateral (side-to-side) movement of the control stick or a turning motion of the wheel and yoke. The ailerons are interconnected in the control system to work simultaneously in opposite directions to one another. As one aileron moves downward to increase the lift of its wing, the other aileron moves upward to decrease the lift of the opposite wing. The opposing action results in controlled movement or roll about the longitudinal axis due to unequal forces. Figure 260 illustrates a typical aileron control system.

164. Secondary Group Control Surfaces

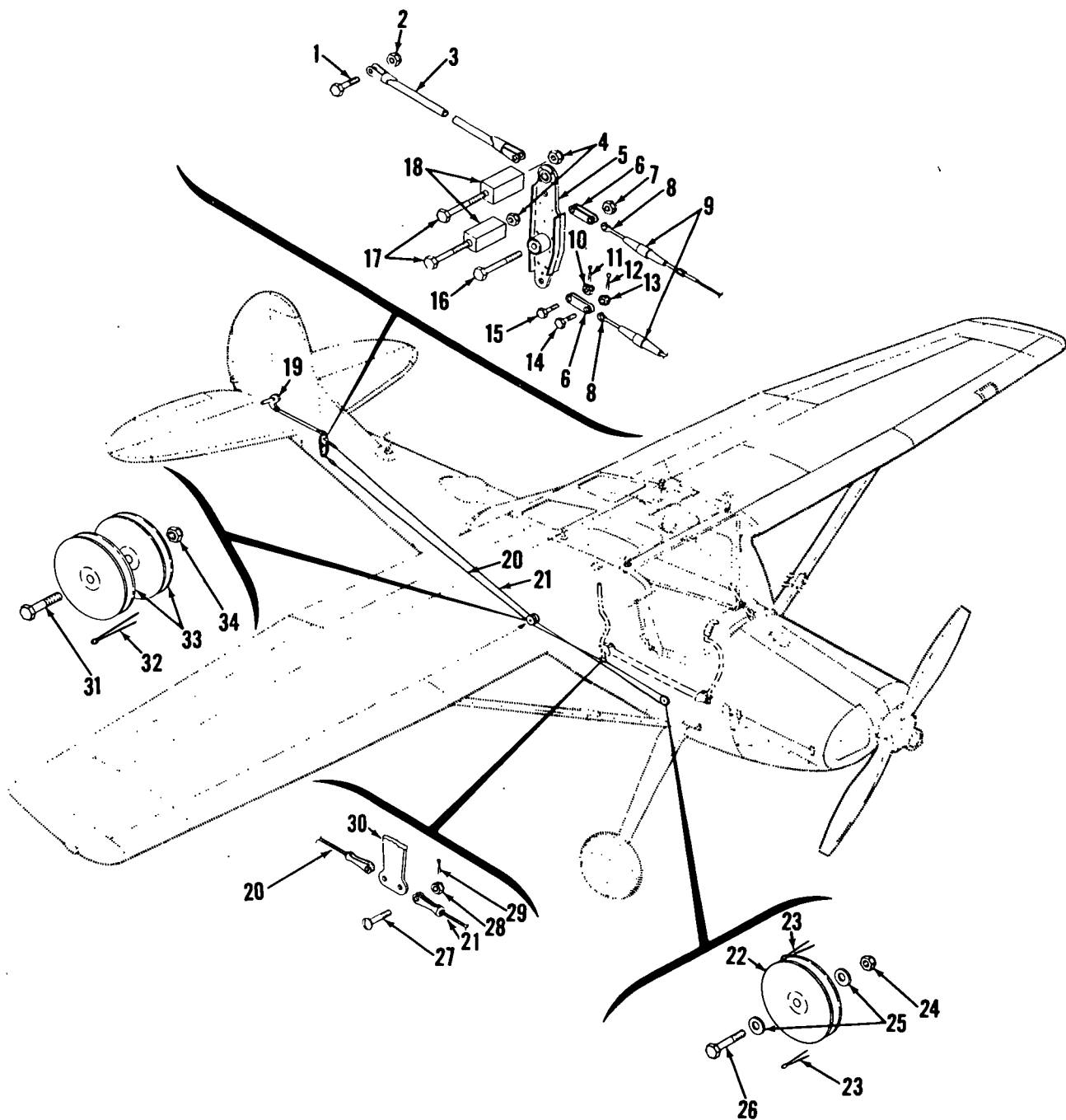
a. Trim Tabs. Trim tabs are hinged to the primary control surfaces, but are operated independently by a separate control. Their purpose is to enable the pilot to trim out an unbalanced

condition without exerting pressure on the control stick or rudder pedals. Trimming is accomplished by setting the tab in the opposite direction to that in which it is desired for the parent primary control surface to be moved. The air-flow striking the trim tab causes the primary surface to move to a position that will correct the unbalanced condition. *For example*, to trim out a nose-heavy condition, the elevator trim tab is set in the DOWN POSITION. This causes the elevator to be moved and held in the UP position, which, in turn, causes the tail of the airplane to be lowered. Figure 261 illustrates a typical control system for elevator trim tabs.

b. Spring Tabs. Spring tabs are similar in appearance to trim tabs, but serve an entirely different purpose. Spring tabs are used to aid the pilot in moving a primary control. The spring tab linkage is connected to the primary control linkage in such a way that movement of the primary control in one direction causes the spring tab, which is actuated by a spring-loaded push-pull tube assembly, to be deflected in the opposite direction. This provides a balanced condition, thus reducing the amount of force required by the pilot to move the primary control.

165. Auxiliary Group Control Surfaces

a. Wing Flaps. Wing flaps are hinged to the lower surface of the wings, inboard of the ailerons. Their purpose is to give the airplane greater lift at low speeds, thereby shortening landing and takeoff runs. Wing flaps may be manually, electrically, or hydraulically actuated. Figure 262 illustrates a manual wing flap actuating system.



- | | | |
|----------------------|------------------------|----------------------|
| 1 Bolt | 13 Nut | 24 Nut |
| 2 Nut | 14 Bolt | 25 Washer |
| 3 Push-pull tube | 15 Bolt | 26 Bolt |
| 4 Nut | 16 Bolt | 27 Bolt |
| 5 Elevator bellcrank | 17 Bolt | 28 Nut |
| 6 Link | 18 Stop | 29 Cotter pin |
| 7 Nut | 19 Elevator pylon | 30 Aft control stick |
| 8 Turnbuckle eye | 20 Elevator up cable | 31 Bolt |
| 9 Turnbuckle barrel | 21 Elevator down cable | 32 Cotter pin |
| 10 Nut | 22 Pulley | 33 Pulley |
| 11 Cotter pin | 23 Cotter pin | 34 Nut |
| 12 Cotter pin | | |

Figure 258. Elevator control system.

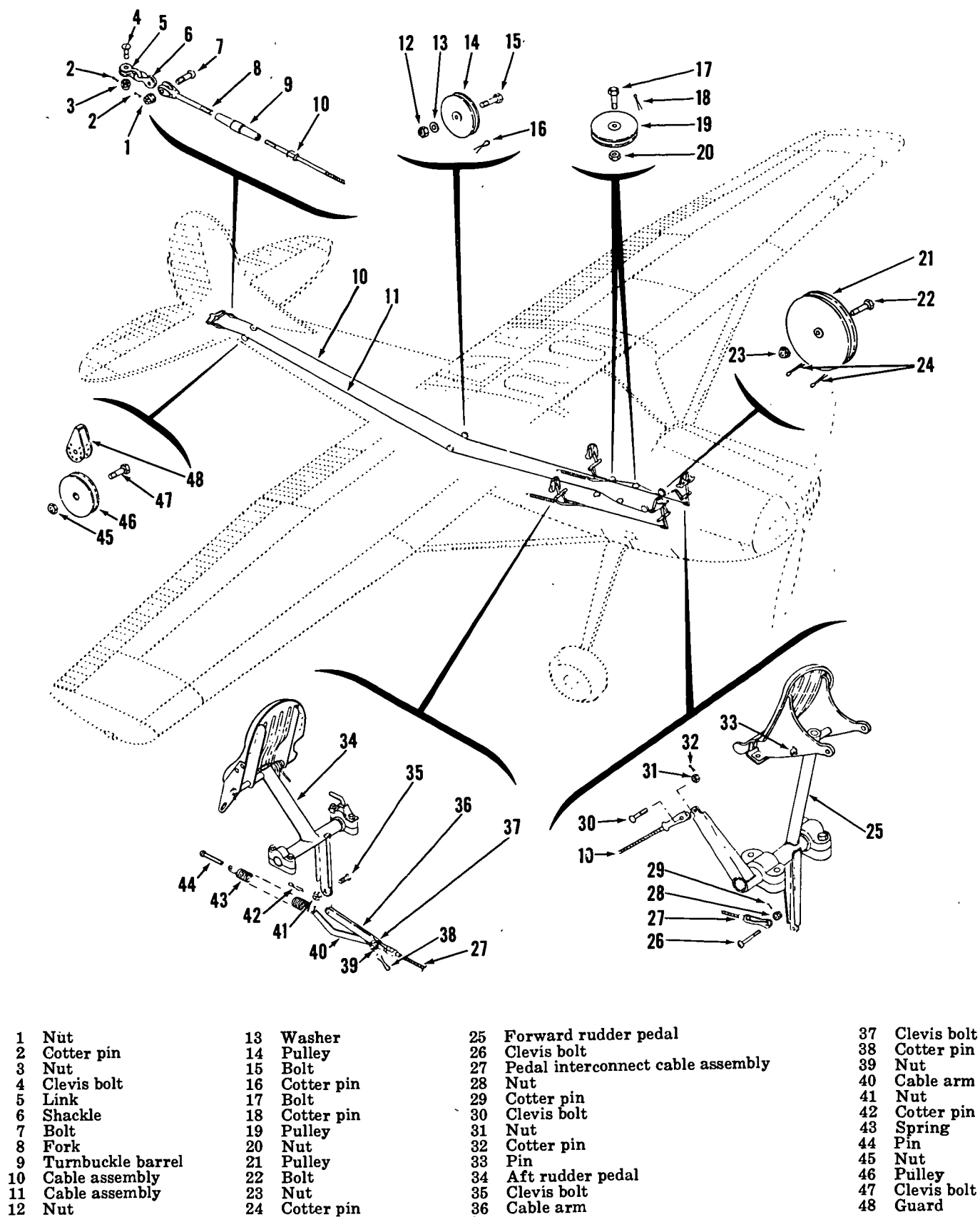
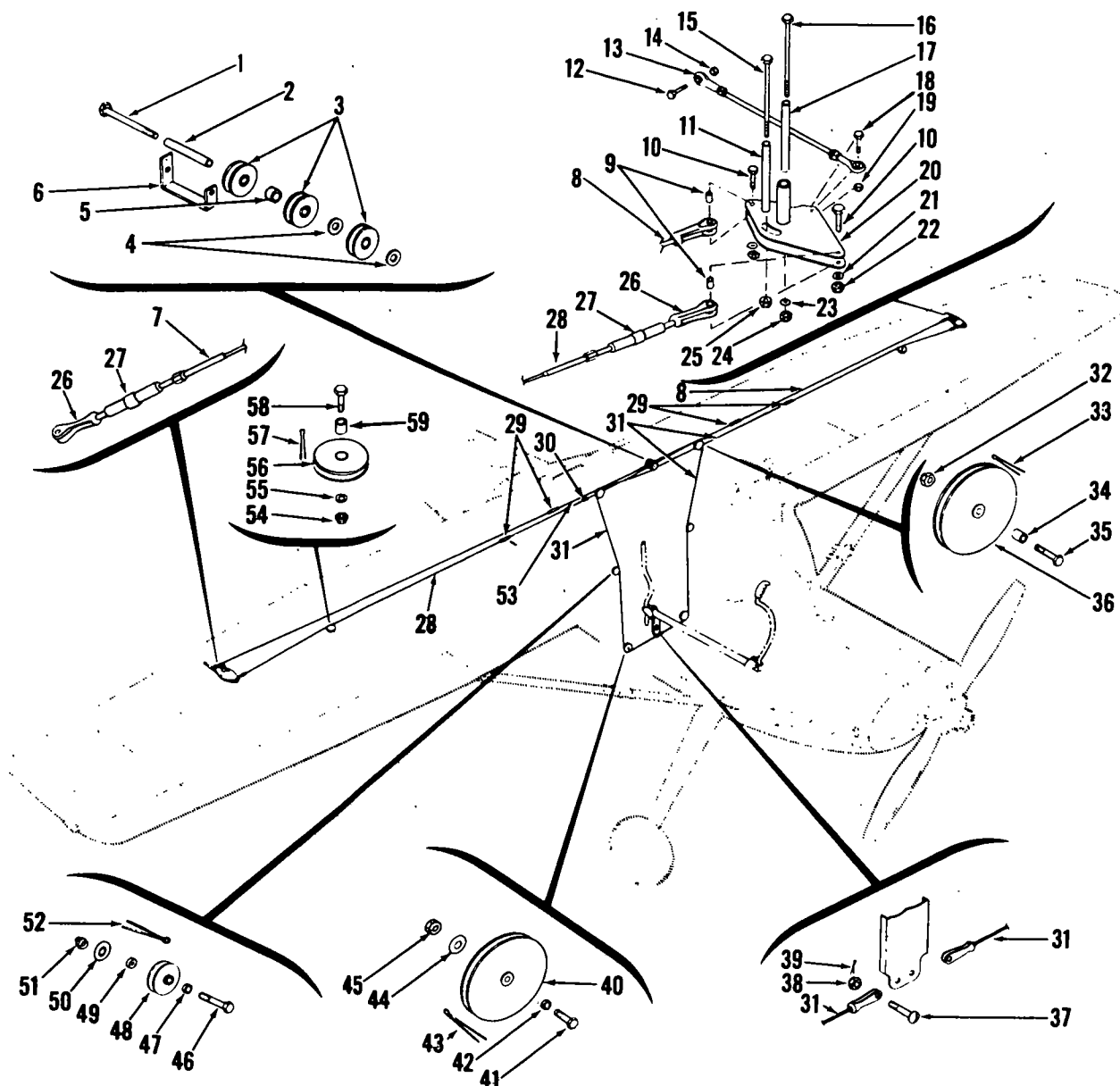
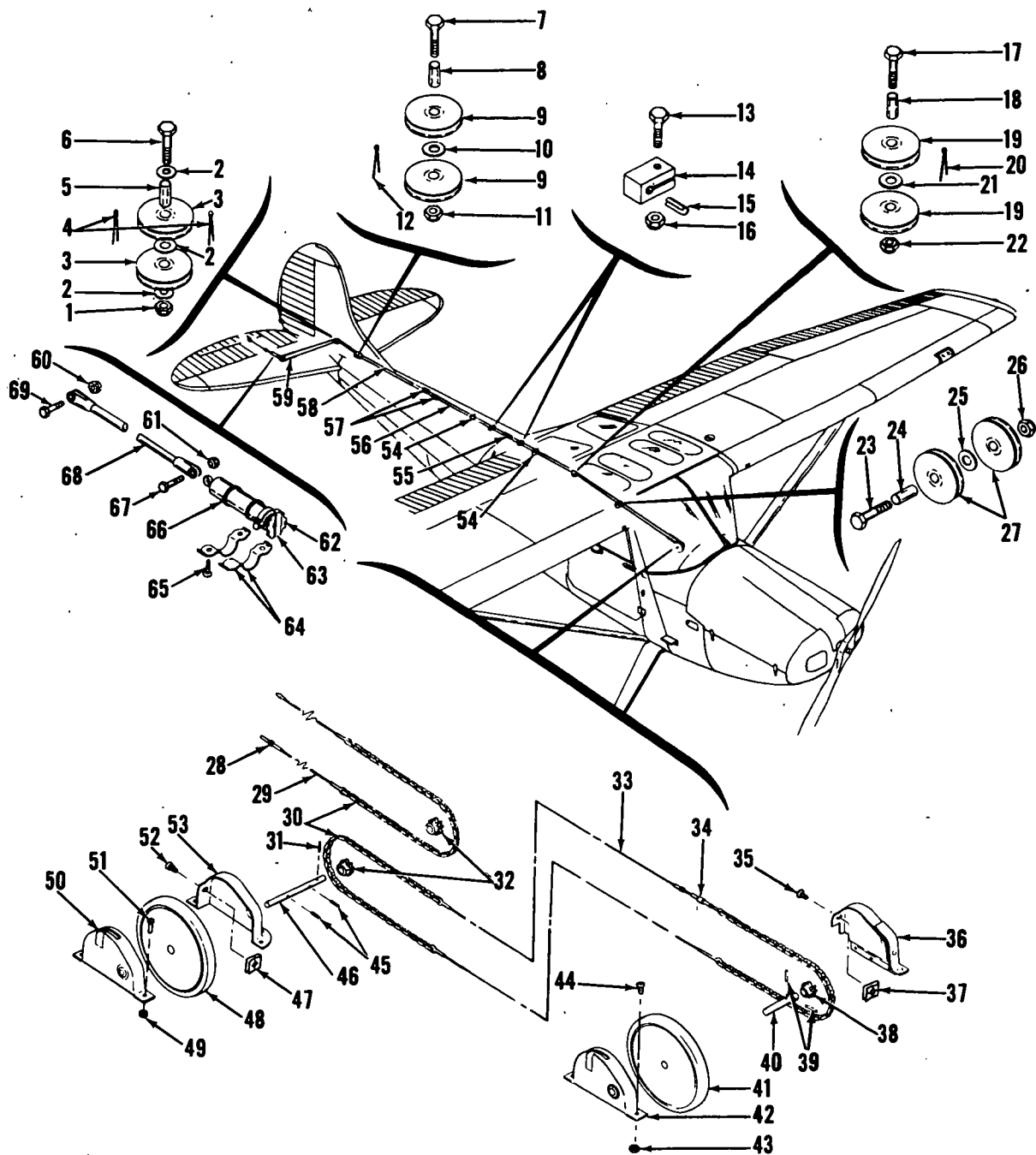


Figure 259. Rudder control system.



- | | | | |
|-------------------------------|----------------------|--------------------------|------------------------------|
| 1 Bolt | 15 Bolt | 31 Fuselage direct cable | 46 Bolt |
| 2 Bushing | 16 Bolt | 32 Nut | 47 Spacer |
| 3 Pulley | 17 Bushing | 33 Cotter pin | 48 Pulley |
| 4 Washer | 18 Bolt | 34 Bushing | 49 Spacer |
| 5 Spacer | 19 Nut | 35 Bolt | 50 Washer |
| 6 Guard | 20 Bellcrank | 36 Pulley | 51 Nut |
| 7 Right wing carry-thru cable | 21 Washer | 37 Bolt | 52 Cotter pin |
| 8 Left wing carry-thru cable | 22 Nut | 38 Nut | 53 Fuselage carry-thru cable |
| 9 Bushing | 23 Washer | 39 Cotter pin | 54 Nut |
| 10 Bolt | 24 Nut | 40 Pulley | 55 Washer |
| 11 Bellcrank stop bushing | 25 Nut | 41 Bolt | 56 Pulley |
| 12 Bolt | 26 Fork | 42 Spacer | 57 Cotter pin |
| 13 Push-pull tube | 27 Turnbuckle barrel | 43 Cotter pin | 58 Bolt |
| 14 Nut | 28 Wing direct cable | 44 Washer | 59 Bushing |
| | 29 Quick disconnect | 45 Nut | |
| | 30 Fairlead | | |

Figure 260. Aileron control system.



- | | | | |
|---------------|---|---------------------------|-----------------------------------|
| 1 Nut | 19 Pulley | 36 Outboard half of cover | 54 Fairlead |
| 2 Washer | 20 Cotter pin | 37 Nut | 55 Turnbuckle |
| 3 Pulley | 21 Washer | 38 Sprocket | 56 Chain and cable assembly |
| 4 Cotter pin | 22 Nut | 39 Roll pin | 57 Quick disconnect |
| 5 Bushing | 23 Bolt | 40 Shaft | 58 Cable assembly |
| 6 Bolt | 24 Bushing | 41 Forward control wheel | 59 Chain |
| 7 Bolt | 25 Washer | 42 Inboard half of cover | 60 Nut |
| 8 Bushing | 26 Nut | 43 Nut | 61 Nut |
| 9 Pulley | 27 Pulley | 44 Screw | 62 Sprocket |
| 10 Washer | 28 Turnbuckle | 45 Roll pin | 63 Chain guard |
| 11 Nut | 29 Cable assembly | 46 Shaft | 64 Clamp |
| 12 Cotter pin | 30 Chain assembly | 47 Nut | 65 Screw |
| 13 Bolt | 31 Roll pin | 48 Aft control wheel | 66 Elevator tab actuator assembly |
| 14 Stop block | 32 Sprocket | 49 Nut | 67 Bolt |
| 15 Bushing | 33 Interconnecting chain and cable assembly | 50 Inboard half of cover | 68 Push-pull tube |
| 16 Nut | 34 Turnbuckle | 51 Screw | 69 Bolt |
| 17 Bolt | 35 Screw | 52 Screw | |
| 18 Bushing | | 53 Outboard half of cover | |

Figure 261. Elevator trim tab control system.

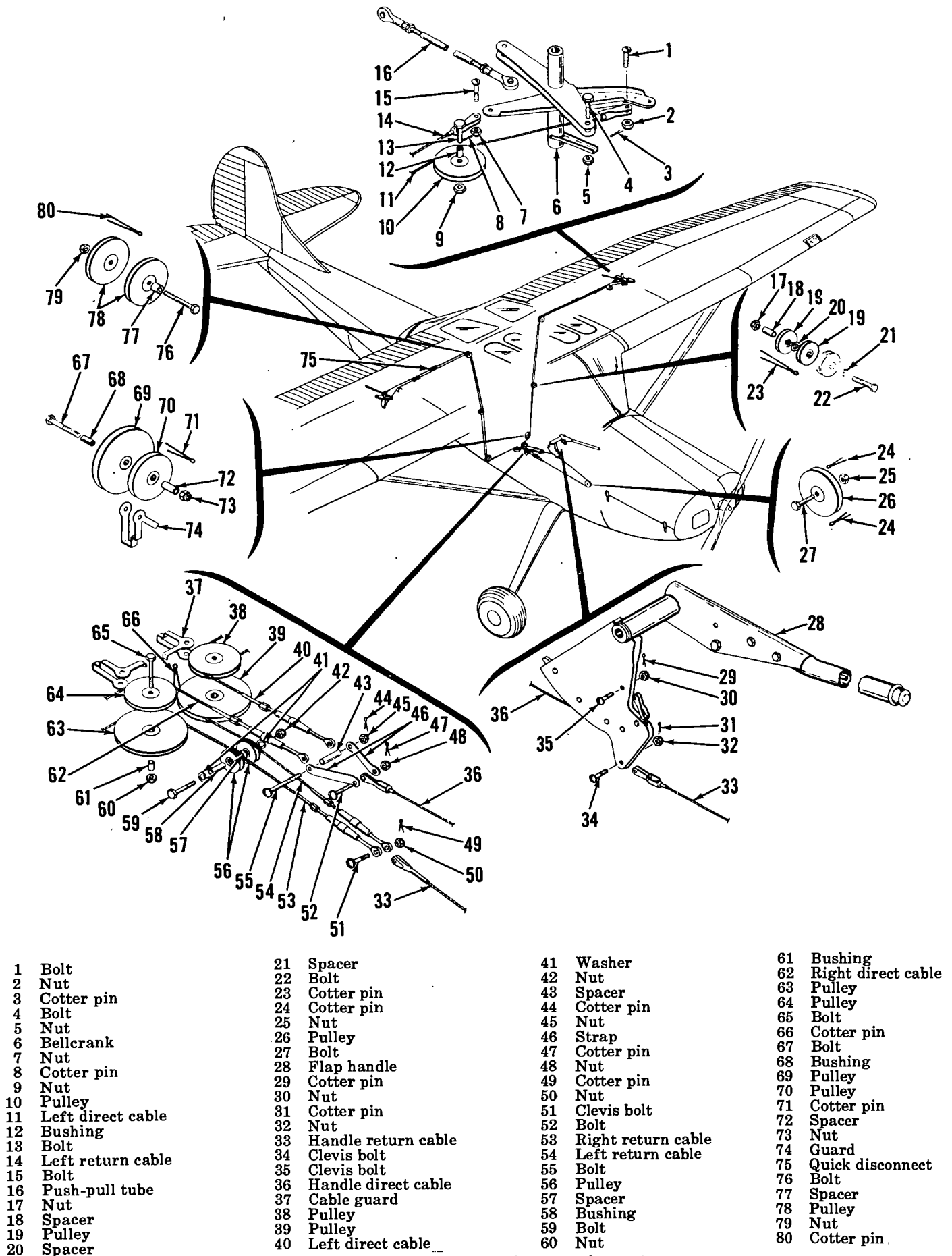


Figure 262. Manual wing flap actuating system.

b. Speed Brakes. Speed brakes are hinged, movable control surfaces attached to the fuselage or to the wings. The primary purpose of speed brakes is to keep the speed of the airplane from building up too high during a dive. They are also used in reducing the landing speed.

c. Slats. Slats are movable control surfaces attached to, and forming part of, the leading edge

of the wing. When the slat is in the open position (extended forward), a slot is created between it and the wing leading edge. This improves handling characteristics at low speeds, allowing the airplane to be controlled laterally at speeds below the otherwise normal stalling speed. Figure 263 illustrates a typical slat installation.

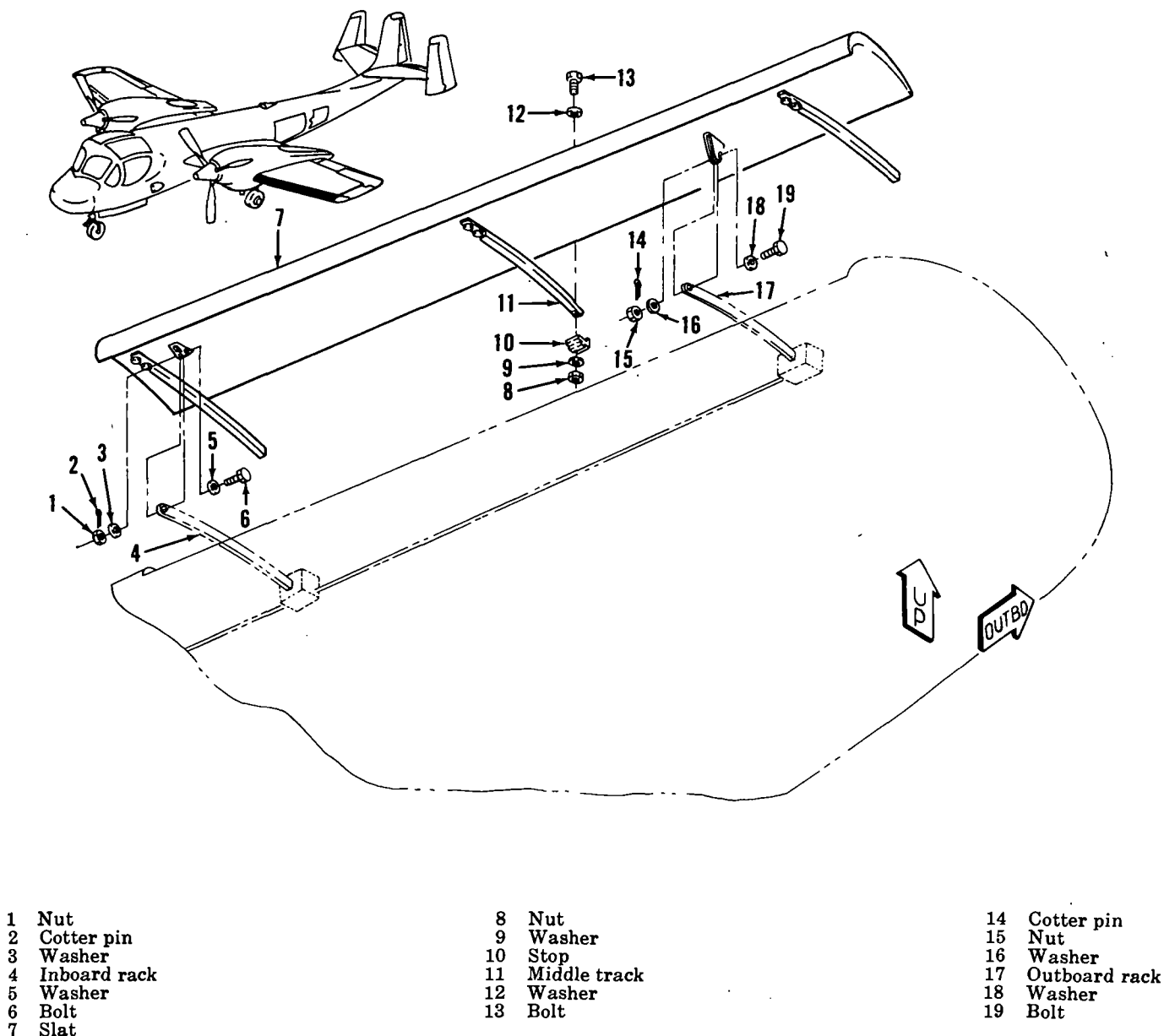
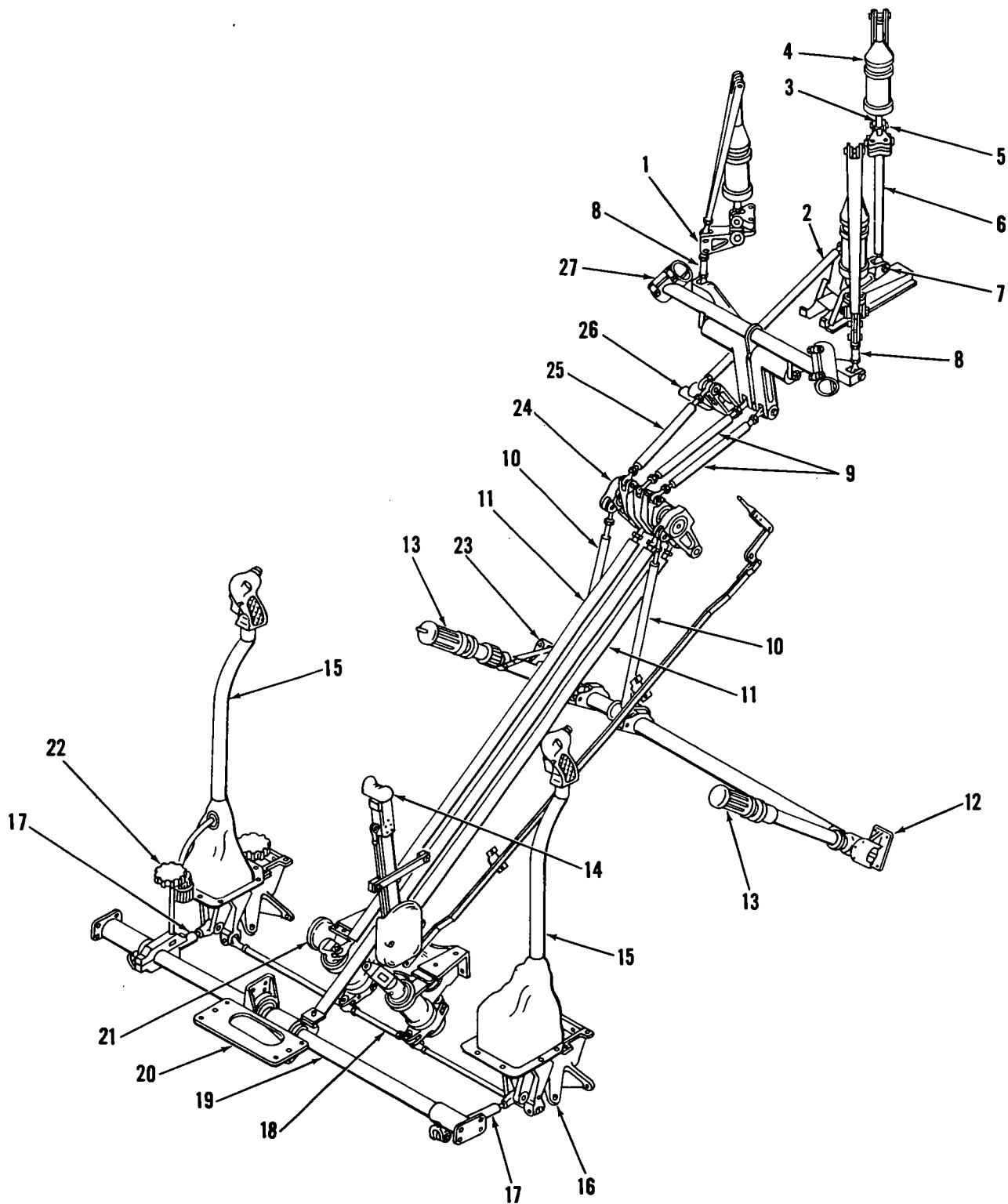


Figure 263. Slat installation.



- | | | | |
|---------------------------|-----------------------------------|------------------------------|---------------------------------|
| 1 Lever assembly | 8 Rod assembly | 14 Rotor brake handle | 21 Emergency servo installation |
| 2 Push-pull tube assembly | 9 Push-pull tube assembly | 15 Cyclic control stick | 22 Friction adjustment knob |
| 3 Push-pull tube assembly | 10 Pitch control rod assembly | 16 Housing and yoke assembly | 23 Weld assembly |
| 4 Servo unit | 11 Push-pull tube assembly | 17 Push-pull tube assembly | 24 Mixing unit |
| 5 Lever assembly | 12 Support assembly | 18 Torque shaft and support | 25 Push-pull tube assembly |
| 6 Push-pull tube assembly | 13 Collective pitch control stick | 19 Torque tube assembly | 26 Bellcrank |
| 7 Bellcrank | | 20 Support and stop | 27 Clamp |

Figure 264. Main rotor control system.

Section II. FLIGHT CONTROL SURFACES AND SYSTEMS OF HELICOPTERS

166. Cyclic Pitch Control

The cyclic pitch control is similar to the control stick of a conventional airplane. It acts through a mechanical linkage to cause the pitch of each main rotor blade to change during a cycle of rotation. The rapidly rotating rotor blades create a disc area that can be tilted in any direction with respect to the supporting rotor mast. Horizontal movement is controlled by changing the direction of tilt of the main rotor to produce a force in the desired direction. Figure 264 illustrates a typical main rotor control system.

167. Collective Pitch and Throttle Control

a. Collective Pitch Control. The collective pitch control varies the lift of the main rotor by increasing or decreasing the pitch of all blades at the same time. Raising the collective pitch control increases the pitch of the main rotor blades, thereby increasing lift. Lowering the control decreases the pitch of the blades, causing a loss of lift and establishing a corresponding rate of descent. Collective pitch control is also used in coordination with the cyclic pitch control to regulate the airspeed of the helicopter.

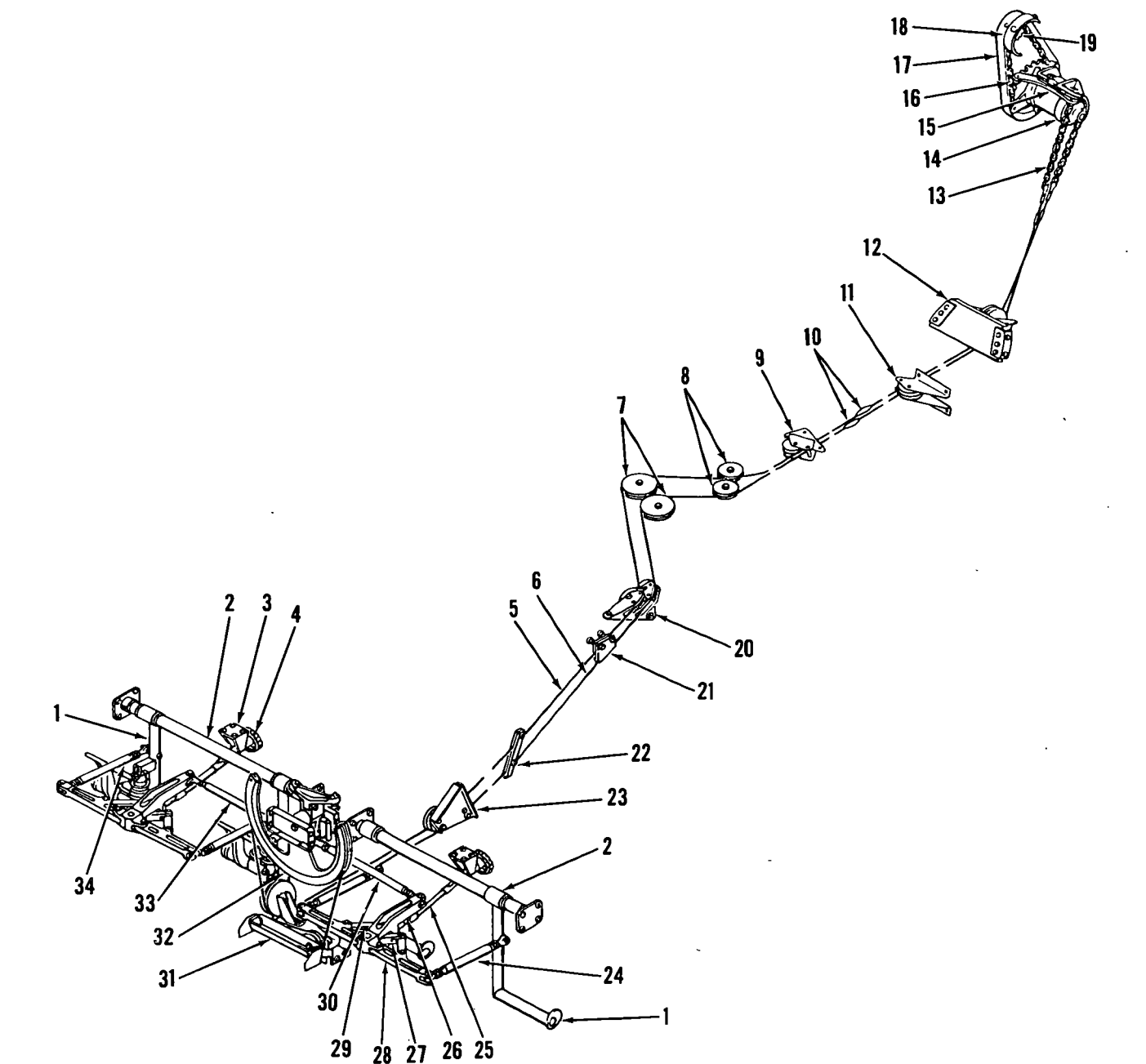
b. Throttle Control. The throttle control is located at the collective pitch grip and is operated by rotating the grip. By manipulating the throttle control, the pilot can maintain a constant engine speed regardless of the increase or decrease in blade pitch. The throttle is synchronized with

the collective pitch control in such a manner that an increase of pitch increases power and a decrease in pitch decreases power.

168. Torque Control

a. Single-Rotor Helicopter. Torque control in the single-rotor helicopter is accomplished by an antitorque rotor called the tail rotor. The tail rotor is driven by a power takeoff from the transmission of the main rotor and runs at a speed having a fixed ratio to the speed of the drive shaft of the main rotor. Two connecting directional control pedals, connected to a pitch-changing device on the tail rotor, are used to counteract torque and to keep the longitudinal axis of the helicopter correctly aligned. Figure 265 illustrates a typical tail rotor control system. Pressure on the left pedal increases the pitch of the tail rotor blades and swings the nose of the helicopter to the left. Pressure on the right pedal decreases the pitch and swings the nose of the helicopter to the right.

b. Tandem-Rotor Helicopter. A torque control problem does not exist in tandem-rotor helicopters, since the two main rotors operate in opposite directions to cancel out the torque reaction. The directional control pedals on tandem-rotor helicopters are connected to the tilting mechanism of both main rotors so that operation of the pedals creates the same flight attitude change as in a single rotor helicopter.



- 1 Directional control pedal
- 2 Torque shaft
- 3 Handle bracket
- 4 Pedal adjustment handle
- 5 Cable assembly
- 6 Cable assembly
- 7 Pulley
- 8 Pulley
- 9 Pulley
- 10 Quick disconnect
- 11 Pulley and bracket assembly

- 12 Pulley and bracket assembly
- 13 Chain assembly
- 14 Torque shaft
- 15 Adapter
- 16 Chain assembly
- 17 Fairing
- 18 Guard
- 19 Sprocket
- 20 Pulley and bracket assembly
- 21 Fairlead
- 22 Fairlead

- 23 Pulley and bracket assembly
- 24 Rod assembly
- 25 Rod assembly
- 26 Bellcrank
- 27 Adjuster
- 28 Arm assembly
- 29 Link
- 30 Rod assembly
- 31 Pulley and bracket assembly
- 32 Quadrant assembly
- 33 Rod assembly
- 34 Rod assembly

Figure 265. Tail rotor control system.

Section III. CABLE LINKAGE

169. General

A cable is a group of wires or strands of wire twisted together to form a wire rope. Cables are used on aircraft to manipulate and regulate control surfaces. The use of cables has many advantages, one of the most important being that their failure is never abrupt, but is progressive over periods of extended use. When cables are used for the manipulation of a unit, they must be used in pairs; one set to move the unit in one direction, and the other to move it in the opposite direction. Since cables are used in pairs and stretched taut, very little play is present between the actuating device and the unit. Consequently, cable-controlled units respond quickly and accurately to control movements.

170. Cable Construction

a. In a cable, the relationship of the direction of twist of each wire or strand to another, and to the cable as a whole, is an important factor in its strength. If the individual strands are twisted in a direction opposite to the twist of strands around the center or core, the cable will not stretch or set as much as one in which they are all twisted in the same direction. This direction of twist (in opposite direction) is most commonly used and is called regular or ordinary lay. Cables may have right regular lay or left regular lay. If the strands are twisted in the direction of twist of the core, the lay is called a lang lay. If the strands are twisted in the direction of twist of the core, the lay is called a lang lay. There is a right and left lang lay. Another twist arrangement is twisting the strand alternately right and left, then twisting them all either to the right or left about the core. This is called reverse lay.

b. When aircraft cables are manufactured, each strand is first formed to the spiral shape to fit the position it is to occupy in the finished cable. This process is called preforming, and cables made by such a process are said to be preformed. Preforming is used to obtain flexibility in the finished cable and to relieve bending and twisting stresses in the strands as they are woven into the cable. It also keeps the cable from spreading when cut.

c. Aircraft control cables are fabricated from flexible, preformed, carbon steel wire or corrosion-resistant steel wire. The smaller corrosion-resistant steel cables are made of steel containing 17 percent chromium and 8 percent nickel. The larger 5/16-, 3/8-, and 7/16- inch cables are made of steel which contains in addition to the chromium and nickel mentioned, not less than

1.75 percent molybdenum. Control cables vary in size from 1/16 to 3/8 inch in diameter. Cables 1/16 and 3/32 inch in diameter are composed of 7 strands of 7 wires each and are referred to as 7 x 7 (1 WRC) cable. Cables 1/8 inch and larger are made up of 7 strands of 19 wires each and are referred to as 7 x 19 (1 WRC) cable. In cable designations, the 1 WRC means one wire rope center. In a 7 strand cable having 1 WRC, six strands are wrapped around a center strand.

171. Cable Fabrication Terms

The following terms are used in discussing cable fabrication:

a. *Cable Size.* Cable size is given in terms of diameter measurement. A cable spoken of as a 1/8-inch cable is 1/8 inch in diameter. The diameter is measured as shown in figure 266. Note that the cable diameter is that of the smallest circle which would inclose the entire cross section of the cable.

b. *Swaging.* The swaging of cable terminals to the cables is done by mechanical means, using either a hand or a power-operated machine. When applied properly, the swaged terminal forms a bond stronger than the cable.

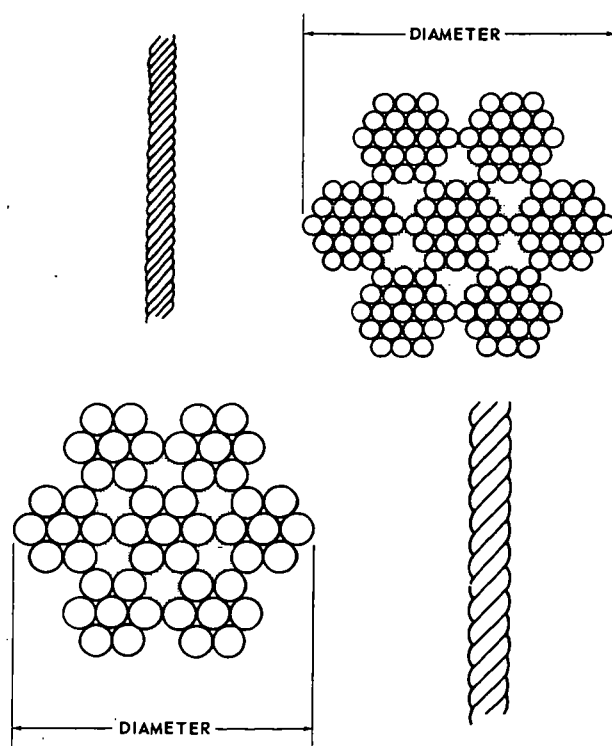


Figure 266. Measuring cable diameter.

c. *Splicing*. Splicing is the joining of two cables or two parts of the same cable by interweaving the separate strands. The joint itself is called a splice. Most joints are now made by swaging since it is faster and provides a stronger joint.

(1) *Long splice*. A long splice is a type of splice in which strands of the cables being joined are unlaidd and cut at intervals. The laidd strands of one cable are fitted into the grooves left by the unlaidd strands of the other.

(2) *Tuck splice*. A tuck splice is a method of joining cable in which the free strands are woven into the standing part of the same cable. It is also a method of joining two cables by weaving the strands of one into the strands of the other.

(3) *Woven splice*. A woven splice is a type of cable joint in which the strands of the free end of the cable are woven into the standing part, after which the splice is served with waxen linen cord and shellacked.

(4) *Wrap-soldered splice*. A wrap-soldered splice is a type of cable joint made by securing the free end of a cable to the standing end by wrapping with a single layer of soft galvanized steel wire, allowing the wrapping wire to extend well over the free end. The joint is then sweat-soldered.

d. *Serving*. Serving consists of wrapping a cable splice with wire or cord. The turns of wire or serving cord are laidd close to each other, forming an almost solid surface. This strengthens and reinforces the splice.

e. *Unlaying*. To unlay a cable is to untwist or separate the strands as in a long splice.

f. *Standing Length and Free End*. The free end is the loose end of a cable which is to be spliced or otherwise attached to the main part or standing length. These terms are illustrated in figure 267.

g. *Tucking*. To tuck means to secure or fasten by pushing the ends of cable strands under other strands.

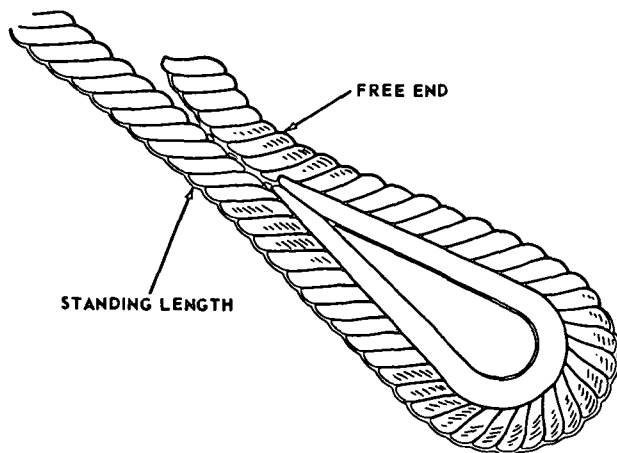


Figure 267. Standing length and free end.

172. Cable Fabrication Hardware

In a cable-type flight control system, a number of different cable hardware items are required as well as the individual sections of cable. Such items may be classified as cable fittings and cable accessories.

a. Cable Fittings.

(1) *Ball type*. A ball-type fitting is a cable fitting in the form of a metal ball, drilled so it can be swaged onto a cable. A shank may protrude from one or both ends so that the fitting may be swaged more securely. The ball may serve as a terminal or a cable stop, or it may be fitted into notches on quadrants or drums to prevent the cable from creeping.

(2) *Bushing*. A bushing is a pulley-like ring used in a cable loop. The outer surface is grooved to fit the cable and the inner surface forms a smooth bearing. Bushings are usually made of corrosion-resistant steel and are available in thicknesses, diameters, depths of grooves, and sizes of hole to conform to the various sizes of cables with which they are to be used.

(3) *Clamp*. A clamp is a fastening device for heavy cables. It consists of two metal pieces, each with two straight parallel grooves. The two pieces are placed one on each side of the standing length and free end with the cable in the grooves and then fastened together with bolts.

(4) *Clevis*. A clevis is a U-shaped terminal fitting by which cables may be fastened to an actuator or to a unit. A clevis pin is used at one end, while the other end of the clevis is attached to the cable by soldering or swaging.

(5) *Clip*. A clip is a U-shaped bolt with a clamp base and nut that is used to clamp the free end of a cable to the standing length. Clips are attached with the bolt over the free end and the base over the standing length.

(6) *Cable eye*. A cable eye is an end or terminal fitting for connecting a cable to another fitting. It may form the end of a swaged fitting. A cable bushing can be considered a cable eye.

(7) *Fork*. A fork is a terminal fitting which has two prongs to fit over the mating prong of a cable eye.

(8) *Shackle*. A shackle is a metal loop by which cables may be attached to a unit. A shackle is usually used in connection with a loop and thimble.

(9) *Socket*. A socket is a fitting with a cone-shaped base into which a cable end can be inserted for fastening. It is equipped with a loop, bar, or fork, to which another connecting device, such as a hook, ring, or loop can be attached.

(10) *Stop*. A stop is a device placed on a cable to limit travel of the cable or of the con-

trol. Stops may be of the ball type, rectangular swaged type, or they may consist of a tapered locking screw and nut assembly. The screw type can be used as an adjustable stop.

(11) *Thimble*. A thimble is a pear-shaped, grooved loop of thin metal around which a cable is bent for splicing. Thimbles reinforce cables and prevent chafing and sharp bends at points of attachment.

(12) *Turnbuckle*. A turnbuckle is a device for joining cable ends and adjusting tension. A turnbuckle assembly consists of a barrel and two connecting fittings, either forked, eye-shaped, or sleeved. The barrel is fitted with left-hand threads at one end and right-hand threads at the other end. Turning the barrel causes both fittings to move in or out simultaneously.

b. Cable Accessories.

(1) *Actuator*. An actuator is a device which sets another item in motion. In a cable control system it is a casting to which cables are attached. Cable quadrants and drums located in the control pedestal are actuators, since motion is transmitted to the cables by them.

(2) *Bellcrank*. A bellcrank is a device used chiefly for changing cable direction or for increasing or decreasing cable travel. A bellcrank may be placed at the end of a cable to serve as an actuator.

(3) *Cable drum*. A cable drum is a cylindrical casting with several grooves about which a cable can be wound so there will be no cable slippage. Drums are used at points where a very slow and sure motion is desired as in the adjustment mechanism for trim tabs.

(4) *Fair-lead*. A fair-lead is a fixture, usually made of plastic, with one or more holes through which cables pass. Fair-leads are used to prevent cables from coming in contact with structural parts of the aircraft and to reduce vibration in long stretches of cable. Pressure seals are used for fairleads where cables pass through pressurized compartments.

(5) *Pulley*. A pulley is a grooved wheel which supplies a rolling bearing at a point where the cable changes direction.

(6) *Quadrant*. A quadrant is a casting to which cables are attached for actuating purposes. The quadrant is actuated by an attached lever, and this action transmits motion through the cable to a drum or an attached pulley which, in turn, causes movement in the unit.

(7) *Sheave*. A sheave is a large pulley which performs functions similar to a bellcrank; that is, reducing or increasing travel distance, and changing direction of cables.

173. Cable Inspection and Fabrication

a. Cable Inspection.

(1) *Broken wires*. The results of tests show that the loss in cable strength due to broken wires depends upon the concentration of breaks at any one point rather than the total number broken in the cable. A cable may have broken wires and still be capable of carrying its designed load. At each regular inspection period, cables should be inspected for broken wires by passing a cloth along the length of the cable. Broken wires are indicated where the cloth is snagged. The applicable maintenance manual for the aircraft being serviced should be referred to for limitations as to the location and number of wires that may be broken and the cable still considered serviceable.

(2) *Corrosion*. The surface of cables should be inspected for corrosion. If corrosion is found on the surface, relieve the tension on the cable and inspect the interior strands. Any corrosion of the interior constitutes failure, and the cable must be replaced. If no interior corrosion is detected, remove loose rust and surface corrosion with a rag or brush moistened with solvent, Federal Specification P-D-680. Clean the cable with steel wool and apply an approved corrosion preventive material.

(3) *Wear*. An inspection of cables may reveal worn spots in the strands. Any 7 x 7 cable showing wear on three or less wires per inch, or any 7 x 19 cable showing wear on six or less wires per inch will be considered serviceable provided no wires are worn more than halfway through the wire diameter, and provided no broken wires are present in the worn area. One less worn wire per inch is allowed for each broken wire in the same inch. The applicable manual for the aircraft being serviced should be consulted for any additional wear limitations.

b. Cable Fabrication. When needed cable assemblies are not available as replacement items, they will have to be fabricated. The following instructions cover cable cutting and the installation of swaged fittings. When swaging equipment is not available, cable assemblies may be prepared by splicing and using the proper substitute fittings.

(1) *Cable cutting*. Cables may be cut by any cutting method, except a torch, depending upon the tools available. If the type cable being cut tends to unravel or fray, the cut area should be sweat-soldered or wrapped with masking, cellulose, or friction tape so that half the soldered or taped width will remain on each end after cutting. The best method of cutting cables is with a cable-cutting machine having special jaws for cables of various diameters. When using a cable-

cutting machine, the cable should be placed in the proper groove and held firmly at right angles to the blade while the handle is pulled down sharply. Small-diameter cables may be cut satisfactorily with a pair of heavy-duty diagonal cutters, side cutters, or with a pair of wire nippers. Best results are obtained by holding the cutting jaws perpendicular to the cable during the cutting operation. A cold chisel, in conjunction with a soft metal block, may also be used for cutting cables. The chisel should be held straight up with the cutting edge at right angles to the cable, and a heavy hammer should be used to effect a clean, square cut.

(2) *Swaging.* The hand-swaging tool (fig. 268) is most commonly used for repair work. Terminals are manufactured to fit a specific cable size and will not fit any other size cable. The cable end should be cut square and clean with all

strands in a compact group. Dip the cable end in a light oil and insert into the terminal barrel to a depth of approximately one-half the barrel length. Kink the cable by bending it toward the terminal approximately 45 degrees; then straighten the cable and push it the remaining distance into the terminal barrel. Kinking the cable provides enough friction to hold the terminal in place until the swaging operation can be performed. Install the proper size dies in the swaging machine for the terminal being used. Insert the terminal and cable end in the swaging machine and perform the swaging operation. After swaging is completed, measure the outside diameter of the barrel to determine if it has been swaged sufficiently. If the terminal is bent more than the allowable 1/2 degree, place it in a vise and straighten it with a mallet or with moderate pressure from the jaws of the vise.

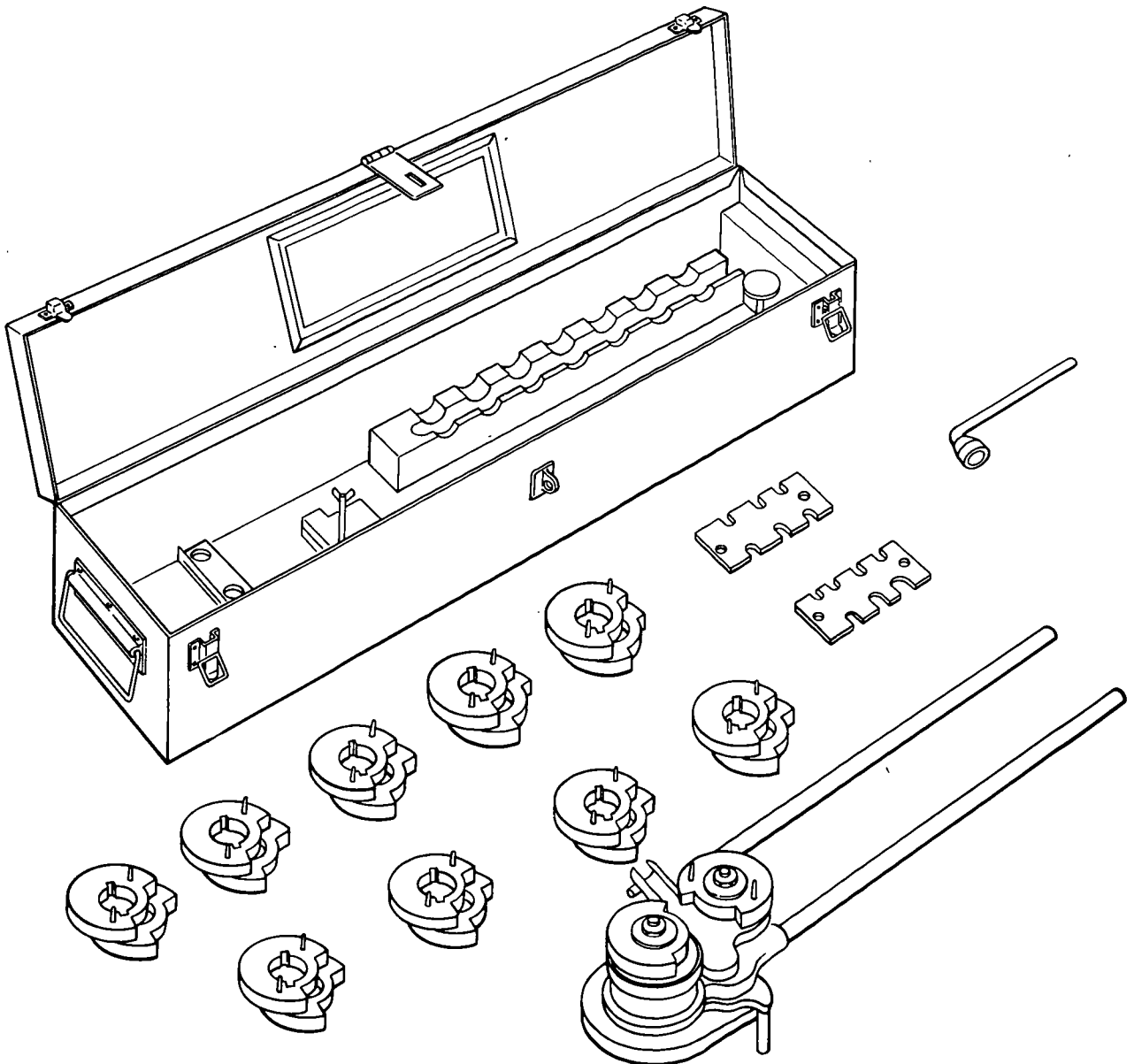


Figure 268. Hand-swaging tools with dies.

Section IV. PUSH-PULL LINKAGE

174. Definition and Purpose

Control rod assemblies are used as links in mechanical systems to allow remote operation and adjustment of components. Push-pull linkage is designed and constructed so that both torsional and compression forces will be transmitted to the component being operated. The two common types of push-pull linkage are the control tube and the control rod. Rod ends are used on the push-pull linkage as attachment points and to effect minor adjustments. Idler arms and bellcranks are used to change direction or amount of control movement. The operation or adjustment of some accessories or flight controls requires a rotating motion which is often accomplished by means of torque tubes. To effect changes in direction of the torque tube, universal joints are required; the most common being the MS20270 and MS20271, which are attached to the tube by bolts or rivets.

175. Push-Pull Tube Assemblies

a. The control tube assembly consists of a metal tube, usually made of steel or aluminum alloy, and two rod ends. One rod end is attached to each end of the metal tube. The metal tube may be swaged, expanded, or reamed at the ends to engage the rod ends. The rod ends are welded or riveted to the tube (fig. 269).

(1) *Inspection.* The inspections given below are common to all control tube assemblies. Refer to applicable manual for inspection criteria for each particular component.

(a) Check for bent or flattened tube.

(b) Inspect tube for nicks, dents, gouges, scores or scratches, corrosion, and cracks.

Note. If doubt exists as to presence of cracks in tube, it must be stripped of paint and a magnetic particle or fluorescent penetrant inspection made. Refer to TM 55-405-7.

(c) Inspect rod ends for security (loose rivets), cracks or breaks, and damaged threaded portions.

(2) *Repair.* Control tubes can be repaired by methods similar to those used on structural members. When repairing a control tube, a perfect straightness must be obtained to preserve the full strength of the tube. Sleeve reinforcements may be added to steel tubes with a scarfed or fish-mouth cut and then welded in place. Aluminum alloy tubes can be repaired in the same manner using rivets for attachments. If at all possible, the tube should be replaced and the terminals salvaged. AN490 threaded rod ends should be replaced because of the difficulty in picking up the original rivet holes.

Note 1. Tube repair should not be attempted if damage occurs in the center one-third of the assembly.

Note 2. When replacing rod ends that are riveted to control tube, rotate tube 90 degrees and redrill prior to riveting.

b. *Rod Ends.* There are several different types of rod ends. Rod ends are available with threaded, clevis, and bearing ends. Rod ends that have internally threaded shanks are used on threaded control rods or control tube assemblies which have threaded rod ends. Other rod ends are used to make up control tube assemblies. Rod ends are used to make adjustments in the length of the control tube and are usually safetied by use of a checknut or lock wire.

(1) *Inspection.* Clean and inspect rod ends as follows:

(a) Inspect rod end for cracks and breaks.

(b) Inspect threaded portions for damaged threads.

(c) Inspect for evidence of corrosion.

(d) Check for bent or misaligned clevis forks and elongated bolt-holes.

(e) Thoroughly clean, inspect, and lubricate bearings as outlined in TM 55-1500-204-25/1.

(2) *Repair.* Minor repairs may be accomplished as follows:

(a) Smooth out small nicks and scratches with a fine abrasive cloth (emery cloth), Federal Specification P-C-451.

(b) Correct minor thread irregularities by chasing threads with a tap or die.

(c) Replace defective bearings.

(d) Major defects will necessitate replacement of the rod end.

c. *Installation.* Installation of the control tube assembly and rod ends will be made as a unit, and adjustments will be made at the time of installation. The applicable manual for the specific aircraft must always be consulted for proper dimensions and settings. General procedures for installation are as follows:

(1) Install checknut on threaded end of rod or tubing assembly and attach rod end to assembly.

(2) Adjust rod end to obtain correct length of control tube assembly and tighten checknut against rod end to prevent its coming loose.

Note. Type AN943 and AN951 internally threaded rod ends are equipped with a witness hole a short distance from the thread end to insure adequate thread engagement when installed on an externally threaded rod end. Proper thread engagement is insured when the threads of the externally threaded rod end can be seen or have completely blocked the hole. If the installation is difficult to

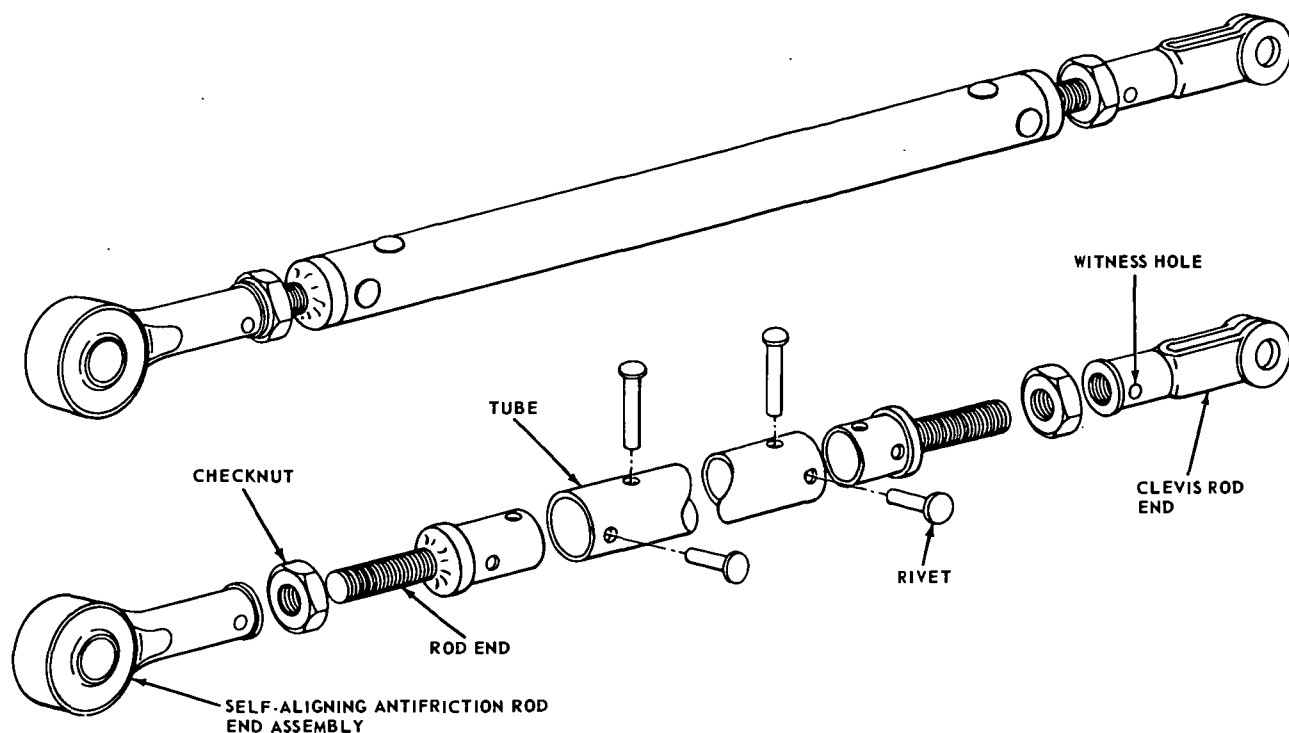


Figure 269. Typical control tube assembly.

check visually, a piece of wire may be inserted in the inspection hole to determine if the rod end has sufficient thread engagement to block the hole.

(3) Install control tube assembly with correct bolts, washers, and nuts.

Note. When connecting a ball bearing rod end, a plain or countersunk washer of appropriate size, NAS143, MS20002, or AN970, will be installed under the attaching nut and bolt head to prevent any possibility of rod end slipping off over the bearing retaining nut or bolt head. The attaching nut and bolt must tightly clamp the inner race of the bearing to the face of the washer and supporting structure. A nut and bolt that is only finger tight does not utilize the bearing for the purpose for which it was intended. Control tubes utilizing clevis rod ends may have washers, if required, installed under the bolt and nut heads on the outside of the fork or between the fork and bearing if space permits. Nuts should be tightened to the torque values listed in the applicable manual.

(4) Check for freedom of movement, full travel, and excessive side play.

(5) Secure rod ends, bolts, and nuts with applicable safety devices.

176. Idler Arms and Bellcranks

a. Inspection. Inspect idler arms and bellcranks for any corrosion, galling, cracks or breaks, worn or loose bearings or mounting bolts, elongated boltholes, and for bent or mutilated condition.

b. Repair. Replace any defective idler arm or bellcrank.

c. Installation. Refer to applicable manual for installation of any particular idler arm or bellcrank.

Section V. RIGGING

177. General

Rigging a control system generally involves a detailed step-by-step procedure which will vary somewhat with different aircraft. The following paragraphs break the entire operation down into three main steps and provide general instructions for accomplishing each step. It will be necessary to consult the applicable aircraft manual before performing any rigging operations.

178. Neutralizing the Controls

Neutralizing a control system is accomplished by securing the pilot's control in the neutral position,

then neutralizing each bellcrank in the system, beginning with the stick bellcrank and working out to the control surface. A control lock is provided for securing the control in the neutral position, and either rig pinholes or index marks are provided at the bellcranks. Neutralize each bellcrank by adjusting the applicable push rod or cable until the rig pinholes or index marks align; then install rig pins. Unless otherwise specified, neutral position means streamlined with the attaching surface (wing or stabilizer). If the control is not in alignment, reference

should be made to the applicable aircraft manual for adjustment procedures.

179. Adjusting Cable Tension

Correct cable tension is necessary in order to obtain proper response from the control surface. Low cable tension may cause sluggishness, free play, flutter, or insufficient travel of the control surface. Excessive cable tension will cause increased system friction and may result in damage to pulleys or bellcranks, or to the cable itself.

a. Installing and Adjusting Turnbuckles. When installing cable system turnbuckles, it is necessary to screw both threaded terminals into the body an equal amount. On initial installation, the turnbuckle terminals should not be screwed far enough into the body to expose more than four body threads. The turnbuckles will be adjusted to provide the proper cable tension. The use of the tensiometer in adjusting cable tension is described in *c* below. After adjustment, not more than three terminal threads should be exposed.

b. Safetying Turnbuckles. After turnbuckles are adjusted for proper cable tension, they will be secured with lock wire or, if clip-type turnbuckles are used, with metal clips. Both methods are described in (1) and (2) below.

(1) *Lock wire.* Insert two pieces of lock wire one-half the wire length into the hole in the center of the turnbuckle barrel. Bend each wire to extend along the top of the turnbuckle toward one end and along the bottom toward the opposite end (fig. 270). Pass the ends of the wires through the hole in the turnbuckle eye or between the jaws of the turnbuckle fork, as applicable, or, if swaged terminals are being secured, through the hole provided in the terminal. Bend the wires toward the center of the turnbuckle and wrap each wire around the shank four times to bind it in place. Zinc-coated, soft steel wire, Federal Specification QQ-W-461, is the standard turnbuckle lock wire. Annealed, corrosion-resisting wire, Federal Specification QQ-W-423, should be used where nonmagnetic or heat-resisting qualities are desired. Where turnbuckles use cables of 3/32-inch or 1/8-inch diameter, 0.041-inch diameter lock wire should be used. On turnbuckles where the cable diameter is 1/16 inch, 0.032-inch diameter lock wire is used. If the cable diameter is greater than 1/8 inch, 0.047-inch diameter lock wire is used. If the hole size in the turnbuckle is not large enough to accommodate the specified wire size, the next smaller size may be used.

(2) *Clip.* Align the slot in the turnbuckle barrel with the slot in the cable terminal. Hold

the lock clip between thumb and forefinger at the loop end and insert the straight end of the clip into the opening formed by aligned slots (fig. 271). Bring the hook end of the lock clip over the hole in center of turnbuckle barrel and seat the hook loop into the hole. Apply pressure to hook shoulder to engage the hook lip in the turnbuckle barrel and to complete safety locking of one end. Repeat the above procedure to safety lock the opposite end. Examine both clips to insure that the hook lip is properly engaged by applying a slight amount of pressure in the disengaging direction.

c. Use of Tensiometer.

(1) *Description.* A tensiometer is used for checking cable tension. This instrument works on the principle of measuring the amount of force required to deflect a cable a certain distance at right angles to its axis. The cable to be tested is placed under the two blocks on the instrument and the trigger is pulled down (fig. 272). This causes the center block, called a riser, to deflect the cable at right angles to the two clamping points. The force required to do this is indicated by a pointer on the dial. Each tensiometer is supplied with a calibration table to convert dial readings to pounds and different risers to be used with different size cables. It should be noted that the calibration table applies to a particular instrument only and cannot be used with any other.

(2) *Application.* The proper procedures for checking cable tension with a tensiometer are outlined as follows:

- (a) Determine size of cable to be tested.
- (b) Refer to calibration chart for riser to be used; select and install proper riser.
- (c) Open trigger and place tensiometer on cable so cable is flush against back of instrument.
- (d) Close trigger and observe reading on dial.
- (e) Convert dial reading to cable tension in pounds by using calibration chart.

(3) *Precautions.* The following precautions should be observed when using a tensiometer:

- (a) Check dial for zero reading before each use.
- (b) Check that correct riser is installed.
- (c) Do not jar or subject tensiometer to sudden shock as instrument will fall out of calibration.
- (d) Check that controls for system being checked are neutralized to insure that cables have an equal loading.
- (e) When taking a blind reading, take several readings at the same spot, since the reading depends on the friction lock holding the correct reading after the instrument is removed.

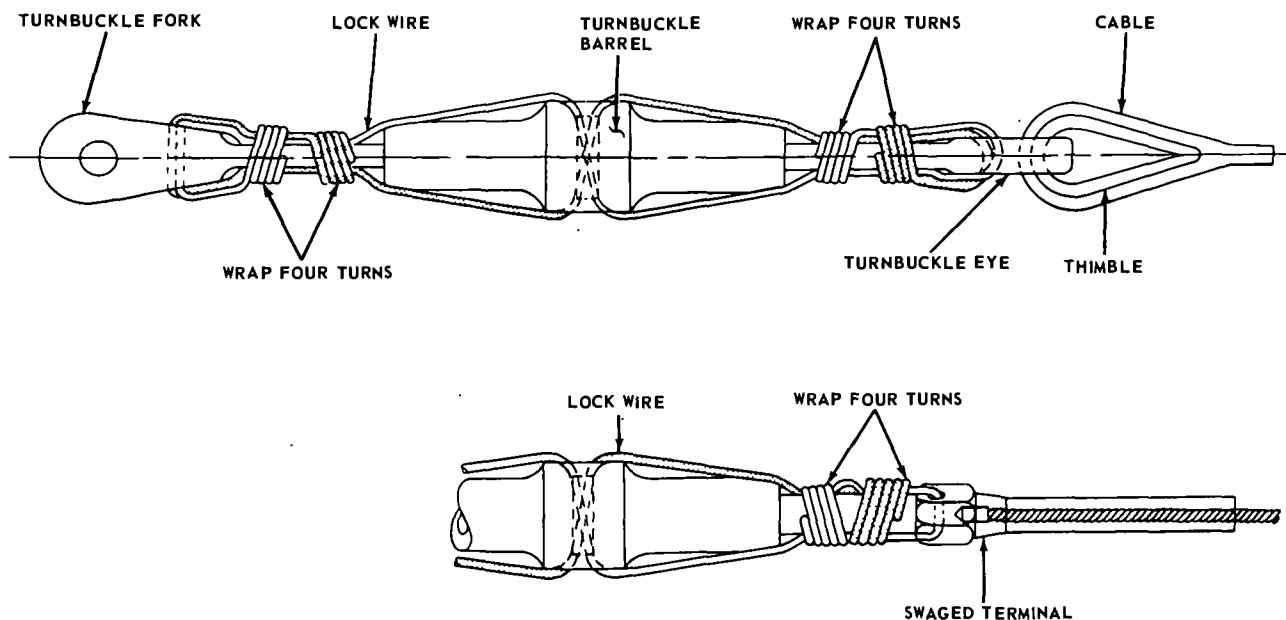


Figure 270. Securing turnbuckle with lock wire.

(f) Do not take readings, within 6 inches of a turnbuckle, quick-disconnect, or any end fitting.

(g) Do not use a tensiometer to check for tensions less than 30 pounds.

(h) Check that serial number on tensiometer is same as serial number on calibration chart.

180. Limiting Control Surface Travel

With high performance aircraft, it is important that not only the correct neutral positions, cable tensions, and rigid attaching points be ascertained, but that the control surfaces have the correct travel in both directions. Due to the various designs and different manufacturers, practically all aircraft will differ in amount of control surface travel. The applicable manual must always be referred to for the correct settings when adjusting the control surface travel.

Note. Particular attention should be given to differences in UP and DOWN, and RIGHT and LEFT travel. Degrees of throw will be measured from the NEUTRAL position.

a. Adjustable Stops for Controlling Travel. Adjustable stops are provided for limiting the throw, or degree of travel, of control surfaces. These stops are usually in the form of a bolt or block installed in a fixed structural member or control component to limit the movement of the entire control system. These stops may be located at various points along the control system and are easily accessible for adjustment purposes. For location of these stops, refer to the applicable manual for the particular aircraft involved.

b. Instructions for Checking Travel. In checking any control system, the system must first be neutralized. If control cables are used, the tension of the cables must be checked as outlined.

(1) *Template.* Templates are often fabricated for each control surface. The template is mounted on and follows the contour of the wing or stabilizer surface. The trailing edge of the template is cut out and the sector part is marked (in degrees from the neutral position) to allow full travel, and measurement of this travel, of the control surface. (a) through (g) below outline a typical adjustment using a template.

(a) Set controls in neutral position.

(b) Remove rigging pins or clamps, if used.

(c) Move control surface to full UP position.

Note. A light pressure must be maintained on the control surface to insure that positive contact with stop is made.

(d) Read degrees, from NEUTRAL, on sector.

(e) Adjust stop by turning stop bolt in or out until desired setting is obtained.

(f) Repeat procedure for DOWN position.

(g) Safety stops to prevent movement from set position.

(2) *Linear measurement.* Control surface travel may be measured by checking the distance the trailing edge moves up or down from the neutral position. Proceed as follows:

(a) Set control in NEUTRAL position and record distance from indexed point on trailing edge of control to fixed point on ground.

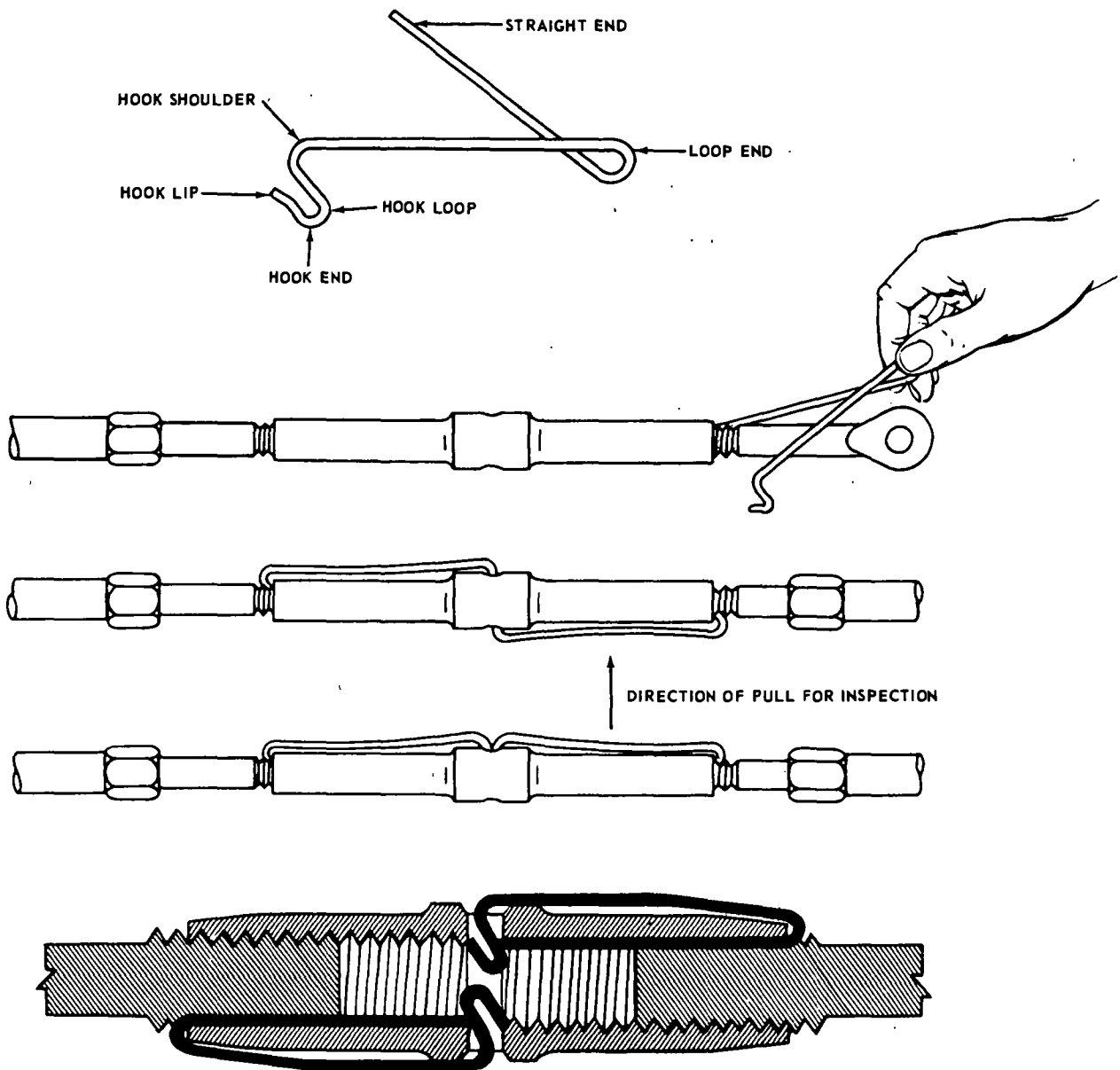


Figure 271. Securing clip locking turnbuckle.

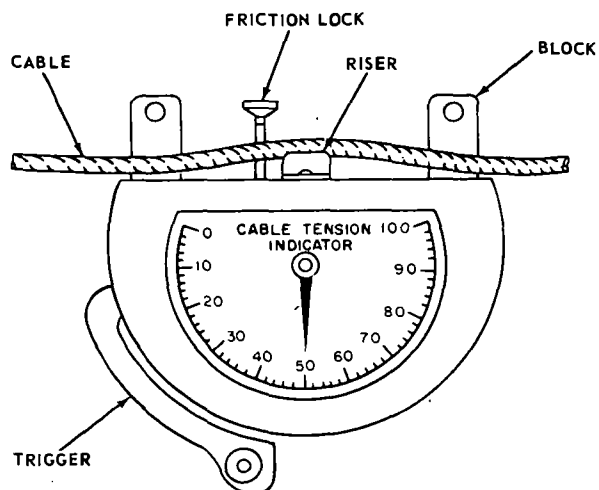


Figure 272. Tensiometer.

(b) Move control surface to full UP and full DOWN positions and measure distance from indexed point on trailing edge to fixed point on ground.

(c) Measure and record distances from NEUTRAL to UP and DOWN positions.

(d) Measure distance from control surface pivot point to indexed point on trailing edge (chordwise) and record.

(e) Determine, by triangulation, the correct distance necessary to set travel to desired settings.

(f) Adjust stops and safety.

Note. Distances may be given in applicable manual. If given, figuring degrees by triangulation is unnecessary.

(3) *Protractor.* Of the three methods commonly used for measuring the degree of travel

of a control surface, the bubble protractor method is probably the most widely used. The protractor assembly (fig. 273) consists of an aluminum frame in which a steel ring and a disc are mounted.

Spirit levels are mounted on both the frame and the disc, and locks are provided for locking the ring to the frame or the disc. Scales are marked on the disc and the ring and the zeros of the scale provide reference marks between which the angle may be read. Hand-adjusting screws are provided so that the ring and the disc may be rotated in relation to the housing and to each other. (a) through (k) below outline the use of the protractor assembly in measuring degrees of travel.

(a) Place control surface in neutral position.

(b) Lock ring to disc at zero by dropping lockpin in deepest slot.

(c) Place protractor assembly approximately in middle of surface next to rib. Mark position for future use.

(d) Using ring adjusting screw, align bubble in level to its center position.

(e) Turn lock for ring until it is finger-tight and record degree reading.

(f) Move control surface to full UP position and place instrument in same position on surface as before.

(g) Release the disc-to-ring lock.

(h) Turn disc adjusting screw until bubble in level is centered.

(i) Remove instrument from surface and read throw in degrees.

(j) Repeat above procedure for DOWN position.

(k) Adjust stops for desired throw and safety all stops if required.

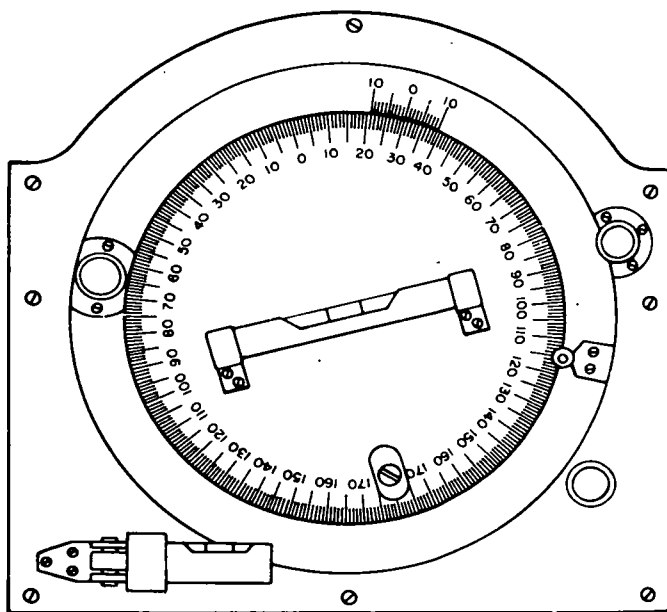


Figure 273. Propeller protractor.

CHAPTER 11

REBALANCING OF MOVABLE SURFACES

Section I. GENERAL

181. Control Surface Balancing

When repairs on a control surface add weight fore or aft of the hinge centerline, the control surface must be rebalanced. Any control surface that is out of balance will not be stable and therefore will not remain in a streamlined position during normal flight. An example would be an aileron that is trailing-edge heavy; it would move down when the wing deflects upward and up when the wing deflects downward. Such a condition can cause unexpected and violent maneuvers of the aircraft. In extreme cases, fluttering and buffeting may develop to a degree that could

cause complete loss of the aircraft. The instructions in this chapter are general. For balancing control surfaces on a specific aircraft, consult the applicable manual for the specific aircraft.

182. Static and Dynamic Balance

Balancing a control surface concerns both static and dynamic balance. When a movable control surface is functioning properly, it is in static and dynamic balance. If a control surface is statically balanced correctly, it will also be dynamically balanced.

Section II. GENERAL CONSIDERATIONS IN BALANCING SURFACES

183. Static Balance

Static balance is the tendency of an object to remain stationary when supported from its center of gravity. There are two ways in which a control surface may be out of static balance; these are called underbalance and overbalance.

a. When a control surface is mounted on a balance stand, a downward travel of the trailing edge below the horizontal position indicates underbalance. Some manufacturers indicate this condition with a plus (+) sign. Example A of figure 274 illustrates the underbalanced condition of a control surface.

b. An upward movement of the trailing edge above the horizontal position indicates overbalance, as shown in example B of figure 274. This is designated by a minus (-) sign. These signs show the need for more or less weight in the correct area to achieve a balanced control surface, as shown in example C of figure 274.

c. A tail-heavy condition (static underbalance) causes undesirable flight performance and is not usually allowed. Better flight operations are gained by nose-heaviness (static overbalance). Most manufacturers advocate the existence of nose-heavy control surfaces.

184. Dynamic Balance

Dynamic balance is that condition in a rotating

body wherein all rotating forces are balanced within themselves so that no vibration is produced while the body is in motion. Dynamic balance, as related to control surfaces, is an effort to maintain balance when the control surface is submitted to movement, as on the aircraft in flight. It involves the placing of weights in the correct location along span of the surfaces. The location of the weights will, in almost all cases, be forward of the hinge centerline.

185. Terms and Symbols

The following terms and symbols and their meanings will be useful in the understanding of procedures for balancing, solving of formulas, and location of reference points.

a. *Weight Reaction (W_R)*. Weight reaction (W_R) is the gross or calculated net weight used in calculation of formulas to bring about a balanced condition in a control surface unit or an individual component. It is expressed and recorded to the nearest hundredth of a pound and is obtained with the chord line in a horizontal position (fig. 275). Weight reaction may also be defined as the force (in pounds) that is exerted upon the control surface, causing it to move in a clockwise or counterclockwise direction. Weight reaction, as illustrated in figure 275, is the weight reading of the scale (in pounds) as

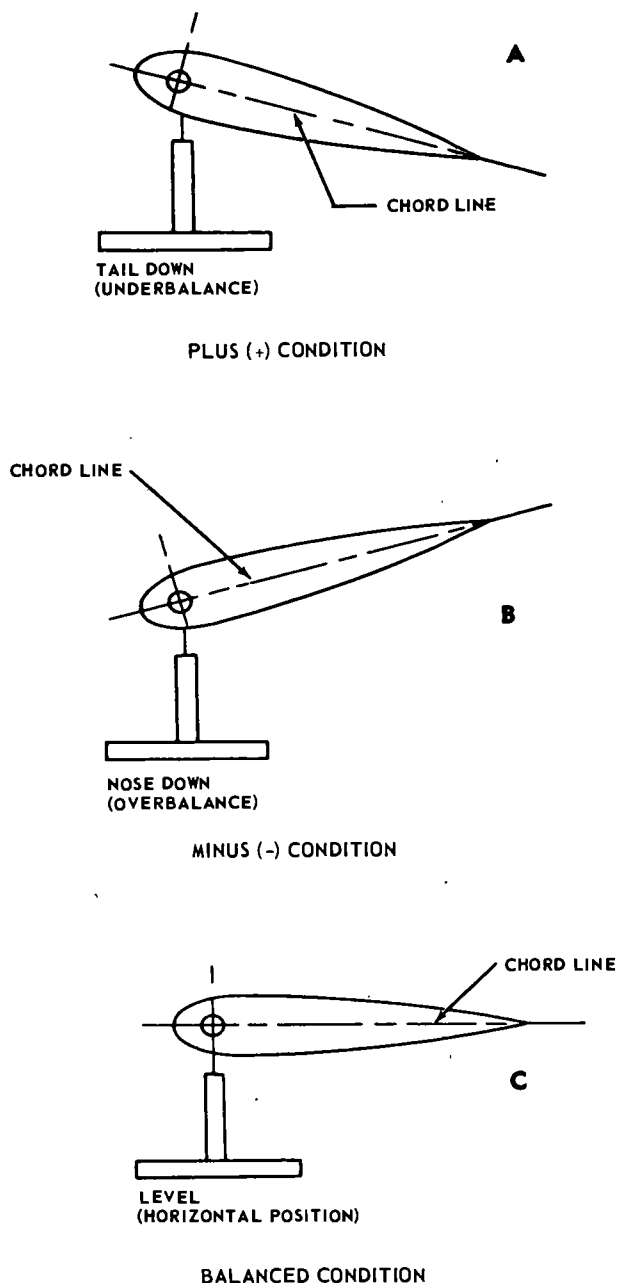


Figure 274. Control surface static balance.

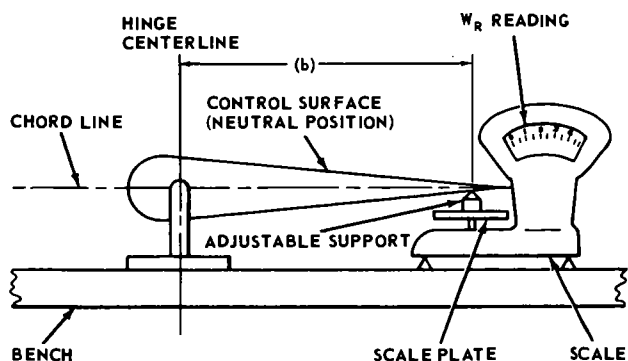


Figure 275. Weighing overbalance or underbalance.

the trailing edge of the control surface exerts pressure upon the adjustable support and scale plate.

b. Control Surface Assembly Weight (W_s). Control surface assembly weight (W_s) is the total weight of a control surface assembly. As an example, in determining the weight for an elevator, the weight of the trim tab assembly, trim tab control pushrod, hinges, bearings, and their attaching parts must be included in the total weight of the elevator assembly.

c. Weight (W). Weight (W) is considered to be the weight of an individual part of a control surface unit, such as the trim tab, trim tab control pushrod, hinge, etc.

d. Panel Weight (W_P). Panel weight (W_P) is the actual weight of a completely balanced panel, including the aft hinge pin and retainer and the forward fabric seal.

e. Center of Gravity (CG). The center of gravity (CG) in balancing of control surfaces is that point at which the control surface may be balanced in any position. It is also the point of load concentration.

f. Hinge Centerline (HC_L). A hinge centerline (HC_L) is the axis about which the control surface rotates (fig. 275).

g. Minus or Negative Sign (-). The minus or negative sign (-) is used as an indication of overbalance. A minus or negative sign preceding a weight reaction (W_R) value indicates that the leading edge tends to move in a downward direction with the control surface in an overbalanced condition.

h. Plus or Positive Sign (+). The plus or positive sign (+) is used as an indication of underbalance. A plus or positive sign preceding a weight reaction (W_R) value indicates that the trailing edge tends to move in a downward direction. This indicates that the control surface is in an underbalanced condition, and the unit must be rebalanced to limits as specified in the applicable manual.

i. Symbol b. The symbol or letter "b" represents the measured distance from hinge centerline (HC_L) to weight reaction (W_R) at the point of the adjustable support or weight. It is referred to as the moment arm b. This distance is measured, expressed, and its value recorded to the nearest hundredth of an inch (fig. 275 and 276).

j. Symbol c. The letter or symbol "c" represents the measured distance from the hinge centerline to the center of the balance weight location. This distance is also measured, expressed, and its value recorded to the nearest hundredth of an inch (fig. 276). Normally, this distance will be forward of the hinge centerline.

k. Moment (M). Moment (M) is the term applied to the combination of force (weight) and distance. Moment (M) is defined as the tendency of a force to cause rotation about a given axis. A simple example is that of a force being

applied with a wrench when turning or tightening a nut. Moment is illustrated in figure 276 as (b) $\times (W_R)$. An example is given at bottom of the figure.

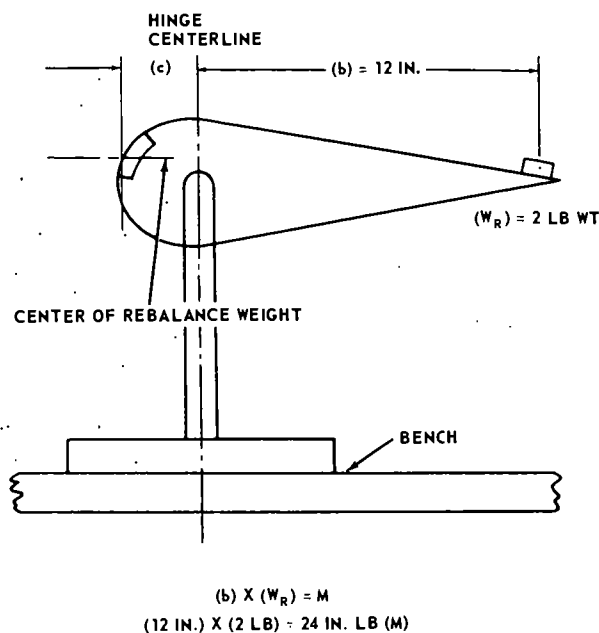


Figure 276. Effects of weight and distance.

Section III. GENERAL BALANCING PROCEDURES

186. Principles of Balancing or Rebalancing

The principles that are essential in the balancing or rebalancing of the control surfaces are not too difficult to understand if some simple comparison is used. For example, a child's seesaw that is out of balance may be compared to a control surface that does not have balance weights installed, as shown in figure 277. From this illustration, it is easy to understand how a control surface is naturally tail (trailing edge) heavy.

a. An underbalanced condition causes a damaging flutter or buffeting of an aircraft and therefore must be eliminated. This is best accomplished by adding weights either inside or on the leading edge of the control surface. When this is properly done, a balanced condition exists and may be compared to the seesaw with a child sitting on the short end of the plank (fig. 277).

b. The effects of moments on control surfaces may be easily understood by a closer observation and study of a seesaw seating two children of different weights in different positions. Figure 278 illustrates a seesaw with an 80-pound child seated at a distance of 6 feet from the fulcrum point of the seesaw. The weight of the child tends to rotate the seesaw in a clockwise

direction until it touches the ground. To bring the seesaw into a level or balanced condition, a child must be placed on the opposite end of the seesaw. The child must be placed at a certain distance and be of an exact weight in order to equalize the moment of the child on the left side of the seesaw.

(1) Assume that a child is placed a distance of 8 feet to the right of the fulcrum point. A simple formula may be used to determine the exact weight the child must be to balance or bring the seesaw into a level condition.

(2) To produce a balanced condition of the seesaw (or control surface), the counterclockwise moment must equal the clockwise moment. Moment is found by multiplying weight times distance; therefore, the formula to balance the seesaw is $W_2 \times D_2 = W_1 \times D_1$.

(3) W_2 would be the unknown weight of the second child. D_2 would be distance, in feet, from fulcrum that the second child is seated (8 feet). W_1 would be the weight of the first child (80 pounds). D_1 would be distance, in feet, from fulcrum that the first child is seated (6 feet).

(4) Finding the weight of the second child is now a simple matter of substitution and solv-

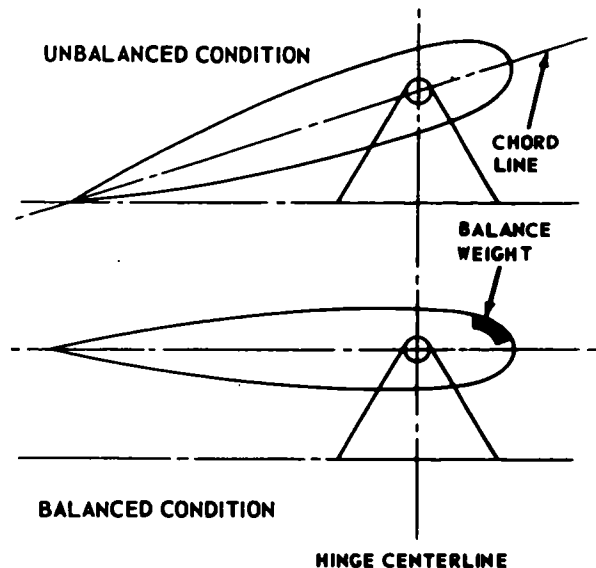
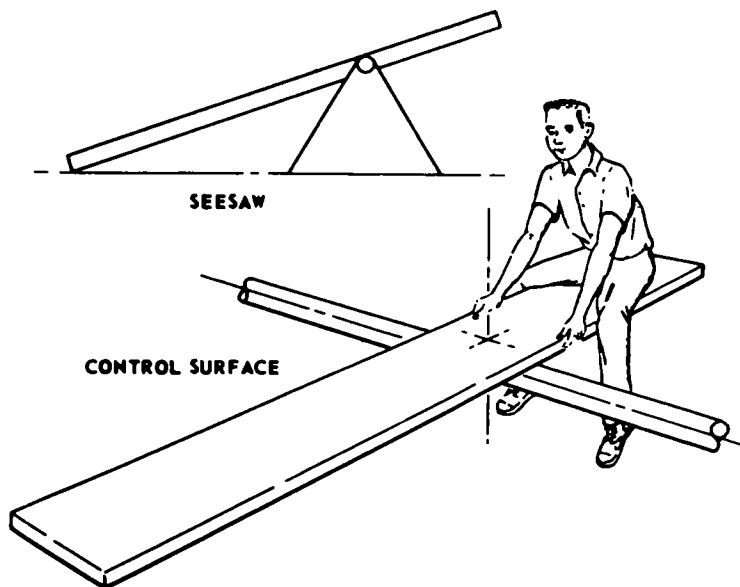
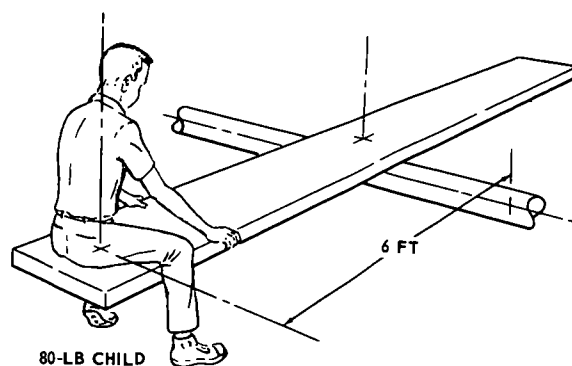


Figure 277. Unbalanced and balanced conditions.



$$\begin{aligned} \text{WEIGHT} \times \text{DISTANCE} &= \text{MOMENT} \\ 80 \text{ LB} \times 6 \text{ FT} &= 480 \text{ FT LB} = \text{MOMENT} \end{aligned}$$

Figure 278. Moment.

ing the formula as follows:

$$\begin{aligned} W_2 \times D_2 &= W_1 \times D_1 \\ W_2 \times 8 &= 80 \text{ pounds} \times 6 \\ W_2 &= \frac{480 \text{ pounds}}{8} \\ W_2 &= 60 \text{ pounds} \end{aligned}$$

(5) The weight of the second child would have to be 60 pounds. To prove the formula:
 $60 \text{ pounds} \times 8 \text{ feet} = 80 \text{ pounds} \times 6 \text{ feet}$

$$480 \text{ foot-pounds} = 480 \text{ foot-pounds}$$

(6) The seesaw is now in a balanced condition, as the counterclockwise moments around the fulcrum are equal to the clockwise moments around the fulcrum.

c. The same effect is obtained in a control surface by the addition of weights forward of the hinge centerline as that obtained by adding the second child on the seesaw. Most of the repairs

to control surfaces are aft of the hinge centerline, resulting in a trailing-edge-heavy condition. The correct balance weight must be calculated and installed in the proper position.

187. Rebalancing Procedures

Repairs to a control surface or its tabs generally increase the weight aft of the hinge centerline, requiring static rebalancing of the control surface system as well as tabs.

a. *Requirements.* The following are requirements which must be met in order to correctly rebalance a control surface.

(1) Control surfaces to be rebalanced should be removed from the aircraft and supported, from their own points, on a suitable stand, jig, or fixture (fig. 279).

(2) Trim tabs on the control surface should be secured in the neutral position when the con-

trol surface is mounted on the stand. The stand must be level and located in an area free of air currents. The control surface must be permitted to rotate freely about hinge points without binding. Balance condition is determined by behavior of trailing edge when the control surface is suspended from its hinge points. Any excessive friction would result in a false reaction as to the overbalance or underbalance of the control surface.

(3) When installing control surface in the stand or jig, a neutral position should be established with chord line of the surface in a horizontal position (fig. 280). Use a bubble protractor (set at the correct angle specified by the applicable manual) to determine the neutral position before continuing balancing procedures.

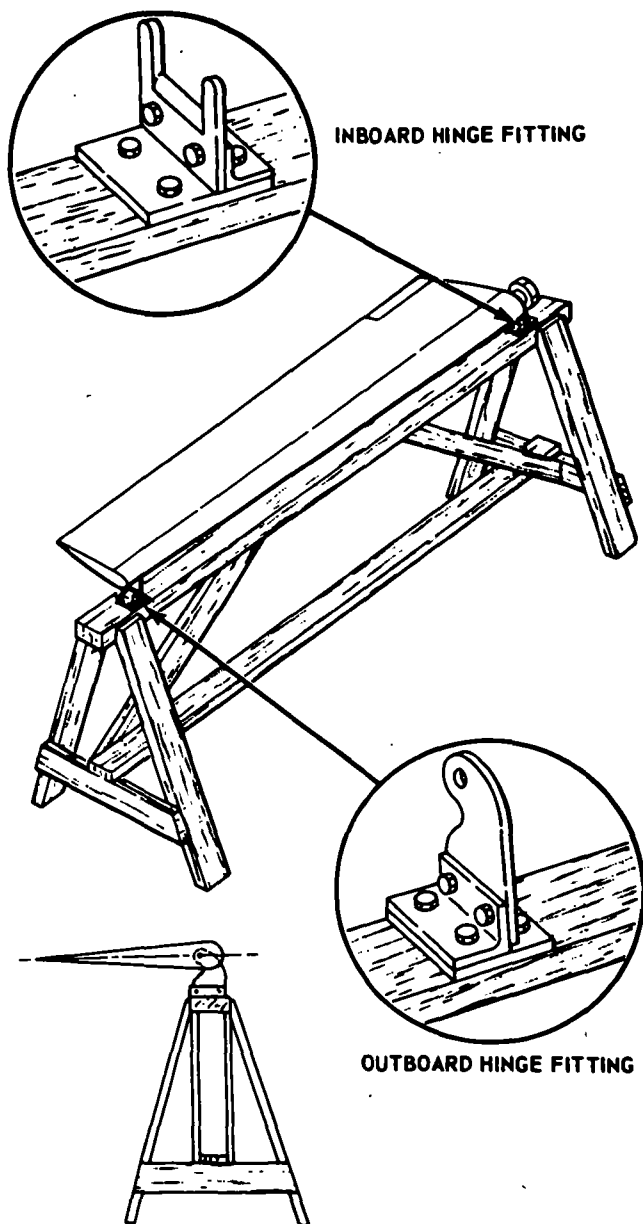


Figure 279. Field-type balancing jig.

Sometimes a visual check is all that is needed to determine whether the surface is balanced or unbalanced.

(4) Any trim tabs or other assemblies that are to remain on the control surface during balancing procedures should be in place. Also, if manuals specify that any assemblies or parts must be removed before balancing, they should be removed.

b. Methods. At the present time, four methods of balancing or rebalancing control surfaces are in use by the various manufacturers of aircraft. The four methods are commonly called calculation method, scale method, trial weight (trial and error) method, and component method.

(1) *Calculation method.* The calculation method of rebalancing a control surface is directly related to the principles of balancing discussed previously. It has one advantage over the other method in that it can be performed without removing the surface from the aircraft.

(a) In using the calculation method, the airframe repairman must know weight of the material removed from the repair area and weight of the material used to accomplish the repair.

(b) Distance from the hinge centerline to center of the repair area is then measured in inches.

Note. The distance must be measured parallel to the chord line of the surface (fig. 281). This distance must be determined to nearest hundredth of an inch.

(c) The next step is to multiply distance times the net weight of the repair. This result will be in inch-pounds. The applicable manual for the specific aircraft should be consulted to determine any further actions. If the inch-pound result of the calculations is within specified tolerances, the control surface will be considered balanced. If it is not within specified limits, the technical order will specify the needed weights, material to use for weights, design for manufacture, and installation locations for addition of the weights.

(2) *Scale method.* The scale method of balancing a control surface requires the use of a scale that is graduated in hundredths of a pound.

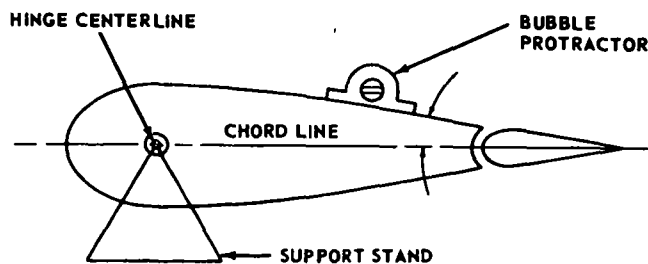


Figure 280. Establishing a neutral position.

changeable with other components on alternate complete units.

c. Fabrication and Installation of Rebalance Weights. After the required rebalance weights have been calculated, they must be fabricated and installed properly. The rebalance weights may be made from fan steel, lead, arch bronze, corrosion-resistant steel, or 4130 steel. The applicable manual for the specific aircraft will normally give the exact dimensions and material to

be used for local manufacture of weights needed to balance control surfaces. The location and amount of clearance needed will determine the size and material of the weight in many cases. The weights of the following metals may be useful in the fabrication of the required balance weights:

(1) Lead	0.41 pounds per cubic inch
(2) Fan steel	0.602 pounds per cubic inch
(3) 4130 steel	0.28 pounds per cubic inch
(4) Corrosion-resistant steel	0.31 pounds per cubic inch

CHAPTER 12

AIRFRAME WELDING

Section I. GAS WELDING, BRAZING, AND SOLDERING

188. General

a. Welding is one of the most practical of the many metal joining processes available to aircraft manufacturers. The welded joint offers rigidity, simplicity, low weight, high strength, and low cost production equipment. Consequently welding has been universally adopted in the building of all types of aircraft. Many structural parts as well as nonstructural parts are joined by some form of welding, and the repair of these many parts is an indispensable part of aircraft maintenance.

b. In addition to the repair of the many aircraft parts and assemblies, there is an almost limitless variety of other welding jobs that must be done within any maintenance activity. Jobs such as fabricating jigs and fixtures and repairing maintenance equipment and machinery are common everyday projects.

189. Gas Welding

a. Gas welding is a fusion process in which heat is supplied by burning a mixture of oxygen and a suitable combustible gas, usually acetylene. A welding torch is used to mix the gases in the proper proportions and to direct the flame against the parts to be welded. The molten edges of the parts then literally flow together and, after cooling, form one solid piece. Usually it is necessary to add extra material to the joint. The correct material in rod form is dipped in and fused with the puddle of molten metal from the parent metal parts.

b. Acetylene is widely used as the combustible gas because of its high flame temperature when mixed with oxygen. This temperature, which ranges from approximately 5,700° to 6,300°F., is so far above the melting point of all commercial metals that it provides a means for the rapid localized melting essential in welding. The oxyacetylene welding and cutting methods are widely used by all types of maintenance activities because the flame is easy to regulate, the gases may be produced inexpensively, and the equipment can be transported easily and safely.

190. Oxyacetylene Welding Equipment

Oxyacetylene welding equipment may be either stationary or portable. A portable outfit can be fastened on a hand truck and pushed around from job to job. It consists of two cylinders, one containing oxygen and one containing acetylene; acetylene and oxygen pressure regulators, complete with pressure gages and connections; a welding torch with a mixing head, extra tips, and connections; two lengths of colored hose, with adapter connections for the torch and regulators; a special wrench; a pair of welding goggles; a flint lighter; and a fire extinguisher. Figure 283 shows a portable outfit mounted on a hand truck. Stationary equipment is similar to a portable outfit except that the acetylene and oxygen are piped to several welding stations from a central supply. Master regulators are used to control the flow of gas and maintain a constant pressure at each station. This is known as a manifold system.

a. Oxygen.

(1) Oxygen is a colorless, tasteless, and odorless gas, slightly heavier than air. It will burn by itself, but will support combustion by combining with other gases. This means that it aids in burning, and this burning gives off considerable heat and light. In its free state, oxygen is one of the most common elements. It makes up about 21 parts in 100 parts of air, while nitrogen accounts for 78 parts. Carbon dioxide and rare gases account for the remainder. It is the presence of oxygen in air that causes rusting of ferrous metals and the discoloration of copper and corrosion of aluminum. This action is known as oxidation. Oxygen unites with the acetylene gas in oxyacetylene welding, causing it to burn, and raising the temperature of the flame to the point where it will melt the metal.

(2) Oxygen is obtained for commercial use by one of two methods:

(a) It may be obtained by the liquid air process, in which atmospheric air is compressed and cooled until it is in a liquid state. In this state the liquid is heated slightly and pure oxy-

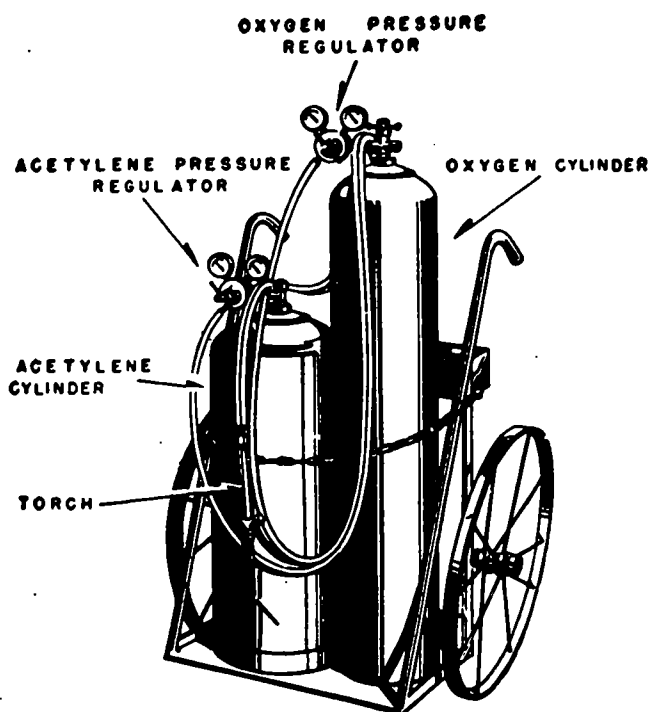


Figure 233. Portable oxyacetylene welding outfit.

gen is distilled out and compressed in cylinders.

(b) Oxygen may be produced by the electrolytic process, in which the hydrogen and oxygen in water are separated by passing a direct current through the water. Hydrogen gas is collected by means of an inverted container at the negative terminal, oxygen at the positive terminal; and each is then piped off and compressed in cylinders.

(3) Oxygen produced for welding operations is called technical oxygen. However, breathing oxygen, which is specially produced for breathing purposes, may also be used.

b. Oxygen Cylinders.

(1) Standard oxygen cylinders used in welding operations are made of seamless steel and come in two sizes. The smaller size holds 200 to 220 cubic feet of oxygen at 1,800 to 2,015 pounds per square inch (psi) pressure; the larger size holds 250 cubic feet of oxygen at 2,265 psi pressure. All oxygen cylinders are painted green for identification. Technical oxygen cylinders are solid green; breathing oxygen cylinders have a white band around the top.

(2) Each oxygen cylinder has a high-pressure valve located at the top of the cylinder. This valve is protected by a metal safety cap which should always be in place when the cylinder is not in use.

(3) Oxygen should never be brought in contact with oil or grease. In the presence of pure

oxygen, these substances become highly combustible. Oxygen hose and valve fittings should never be oiled or greased or handled with oily or greasy hands. Even grease spots on clothing may flare up or explode if struck by a stream of oxygen. Beeswax is the recommended lubricant for oxygen equipment and fittings.

c. Acetylene Gas.

(1) Acetylene is a flammable, colorless gas. It has a distinctive disagreeable odor that is easily detected, even when the gas is greatly diluted with air. Unlike oxygen, acetylene does not exist free in the atmosphere; it must be manufactured. The process is neither difficult nor expensive. Calcium carbide is made to react chemically with water to produce acetylene.

(2) The gas is either used directly in a manifold system or stored in cylinders. If it is ignited in this state, the result is a yellow, smoky flame with a low temperature. When the gas is mixed with oxygen in the proper proportions and ignited, the result is a blue-white flame with temperatures which range from approximately 5,700° to 6,300°F.

(3) Under low pressure at normal temperatures, acetylene is a stable compound; but when compressed in an empty container to pressures greater than 15 psi, it becomes dangerously unstable. For this reason, manufacturers fill the acetylene cylinders with a porous substance (generally a mixture of asbestos and charcoal) and saturate this substance with acetone. Since acetone is capable of absorbing approximately 25 times its own volume of acetylene gas, a cylinder containing the correct amount of acetone can be charged to a pressure of 250 psi without fear of the acetylene becoming unstable.

d. *Acetylene Safety Precautions.* Acetylene safety precautions should be rigidly observed and enforced. Some of the more important things to remember are as follows:

(1) Store acetylene cylinders in an upright position. They must be securely fastened to prevent shifting or falling under any circumstances. Do not lay on sides, drop, or handle roughly. If horizontal stowage is necessary, or an acetylene cylinder is inadvertently left lying in a horizontal position, it must be placed in an upright position for a minimum of 2 hours before using. (Otherwise, acetone in which the acetylene is dissolved will be drawn out with the gas.) Avoid damaging the valves or fuse plugs, since this causes leakage.

(2) Store acetylene cylinders in a well-protected, well-ventilated, dry place, away from heating devices or combustible materials.

(3) Use acetylene from cylinders only

through pressure-reducing regulators. Do not use acetylene at pressures greater than 15 psi.

(4) Open the acetylene valve slowly, 1/4 to 1/2 turn. This will permit an adequate flow of gas. Never open the valve more than 1 1/2 turns of the spindle. Use the special T-wrench provided, and leave it in place on the spindle so that the acetylene may be turned off quickly in an emergency.

(5) Keep sparks, flames, and heat away from acetylene cylinders.

(6) Turn the acetylene cylinder so that the valve outlet will point away from the oxygen cylinder.

(7) Do not interchange hose, regulators, or other apparatus intended for oxygen with those intended for acetylene.

(8) Use only approved hoses and fittings with acetylene equipment. Pure copper, or copper alloys containing 67 to 99 percent copper, must not be used in piping or fittings for handling acetylene (except blowpipe or torch tips). Acetylene reacts with pure or slightly alloyed copper to form cuprous acetylides, a violent explosive.

(9) Test for leaks with soapy water—not with an open flame.

(10) Make no attempt to transfer acetylene from one cylinder to another, refill an acetylene cylinder, or mix any other gas or gases with acetylene.

(11) Keep valves closed on empty cylinders.

(12) Should an acetylene cylinder catch fire, use a wet blanket to extinguish the fire. If this fails, spray a stream of water on the cylinder to keep it cool.

(13) Crack each cylinder valve for an instant to blow dirt out of nozzles before attaching the pressure regulator. Do not stand in front of the valve when opening it.

(14) Learn to identify standard cylinders by color and decals.

e. Acetylene Cylinders. The standard acetylene cylinder is a seamless steel shell with welded ends, approximately 12 inches in diameter and 36 inches long. It is painted yellow and the name of the gas is indicated twice, once on each side of the cylinder, by 2-inch black letters painted lengthwise on the cylinder. A fully charged acetylene cylinder contains 225 cubic feet of gas at pressures up to 250 psi. In the event of fire or any excessive temperature rise, special safety fuse plugs installed in both the top and bottom of the cylinder melt, allowing the excess gas to escape or burn off, thereby minimizing the chances of an explosion. The holes in the safety plugs are made so small that they will not allow the

flames to burn back into the cylinder. Acetylene cylinders should not be allowed to become empty, or a loss of filler material may result. To preclude this loss of filler material, the cylinder should be considered empty when the pressure, through usage, has been reduced to approximately 25 psi.

f. Pressure Regulators.

(1) Acetylene and oxygen regulators reduce pressures and control the flow of gases from the cylinders to the torch. Acetylene and oxygen regulators are of the same general type, although those designed for acetylene are not made to withstand such high pressures as are those designed for use with oxygen. The outlet fitting on acetylene regulators has left-hand threads to prevent interchange of the hoses.

(2) In a portable welding outfit, shown in figure 283, each regulator is equipped with two pressure gage—a high-pressure gage which indicates the cylinder pressure, and a low-pressure gage which indicates the pressure in the hose leading to the torch (working pressure).

(3) In a stationary installation, where the gases are piped to individual welding stations, only one gage for oxygen and one for acetylene are required for each welding station, because it is only necessary to indicate the working pressure of the gases flowing through the hose to the torch.

(4) A typical regulator, complete with pressure gages and connections, is shown in figure 284. The adjusting screw shown on the front of the regulator is for adjusting the working pressure. When this adjusting screw is turned to the left (counterclockwise) until it runs free, the valve mechanism inside the regulator is closed. No gas can then pass to the torch. As the handle is turned to the right (clockwise), the screw passes against the regulating mechanism, the valve opens, and gas passes to the torch at the pressure shown on the working pressure gage. Changes in this pressure may be made at will, simply by adjusting the handle until the desired pressure is registered.

(5) Before opening the valve on a cylinder, the adjusting screw on the regulator should be fully released by turning to the left. As noted above, this closes the valve inside the regulator, thus protecting the mechanism against possible damage.

(6) Regulators are either single-stage or two-stage type. Single-stage regulators reduce the pressure of the gases from cylinder pressure to working pressure in one step or stage. In general, its mechanism consists of a floating valve, a diaphragm, and balancing springs.

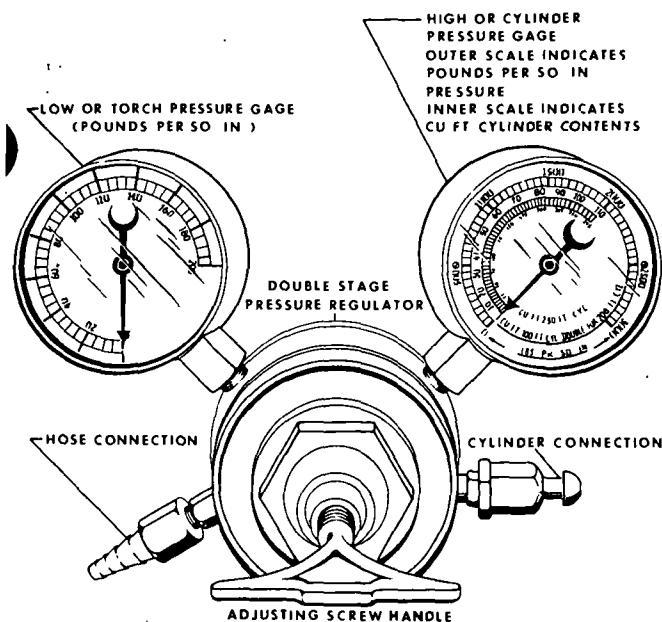


Figure 284. Typical oxygen pressure regulator

(7) In two-stage regulators, the pressure reduction is accomplished in two separate steps. This type of regulator has two independent diaphragm and valve assemblies which make operation extremely efficient. Pressure regulators are available in both the single- and two-stage type. The two-stage type is generally used with portable outfits.

g. Welding Torches.

(1) The welding torch is the unit used to mix the two gases in the proper proportions and to control the volume of the gases and the direction of the flame. The torch has two needle valves—one for adjusting the flow of acetylene. In addition, a handle, two tubes, a mixing head, and a tip are provided. Tips are interchangeable and come in various styles and sizes for welding a wide range of metal thicknesses.

(2) Welding torches may be divided into two principal classes—the balanced-pressure type and the injector type. The balanced-pressure type is also referred to as the medium-pressure torch. The injector type is sometimes referred to as the low-pressure torch. Figure 285 shows the internal construction of the injector type torch.

(3) In the balanced-pressure torch, the oxygen and acetylene both fed to the torch at the same pressure. The openings to the mixing chamber for each gas are equal in size, and the delivery of each gas is independently controlled. This type of torch is generally better suited for aircraft welding than the injector type because of the ease of adjustment and maintenance.

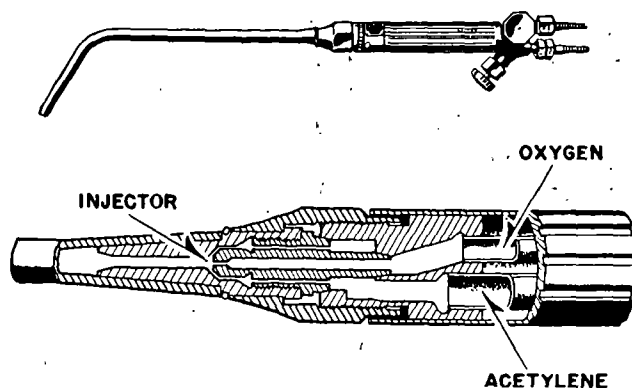


Figure 285. Welding torch.

(4) The injector type torch operates with an acetylene pressure of less than 1 psi and an oxygen pressure from 10 to 40 times greater. In some aircraft welding torches of this type, for example, the ratio of the pressure of the oxygen to the pressure of the acetylene is 20 to 1.

(5) A narrow passageway or nozzle within the torch, called the injector, through which the oxygen passes, causes the speed of oxygen flow to increase to a high velocity with a corresponding drop in pressure. This drop across the injector creates a pressure differential (suction) which acts to draw the required amount of acetylene into the mixing chamber in the torch head.

h. Torch Tips.

(1) The torch tip delivers and controls the final flow of gases. It is important that the correct tip be selected and used with the proper gas pressures if a job is to be satisfactorily welded. The nature of the weld, the material, the experience of the welder, and the position in which the weld is to be made, all determine the correct size of the tip opening. The size of the tip opening, in turn, determines the amount of heat (not the temperature) applied to the work. If a tip which is too small is used, the heat provided will be insufficient to produce penetration to the proper depth. If the tip is too large, the heat will be too great and holes will be burned in the metal.

(2) There is no standard system for indicating the size of the opening in the torch tip; each manufacturer has his own numbering system. A comparison of the tips supplied by various manufacturers appears in table 50. The thickness of the metal for which each tip is adaptable is only approximate, since the nature of the weld, its position, and the conductivity of the metal are all factors in the selection of a torch tip. Such approximations may be used

until you are experienced enough to know which size tip will produce the best weld for each situation.

(3) With use, the torch tip will become clogged with carbon deposits and, if it is brought in contact with the molten pool, particles of slag may lodge in the opening. A split or dis-

torted flame is an indication of a clogged tip. Tips should be cleaned with the proper size twist drill or with a piece of copper or brass safety wire. Fine steel wool may be used to remove oxides from the outside of the tip. These oxides hinder the heat dissipation and cause the tip to overheat.

Table 50. Torch Tip Sizes

Tip size (inches)	Tip drill size	Smith tip No.	Victor tip No.	Airco tip No.	Approximate thickness of steel sheet
0.0200	76	-----	-----	-----	1/64 - 1/32
.0210	75	-----	000	00	1/64 - 1/32
.0225	74	100	-----	-----	1/64 - 1/32
.0250	72	-----	-----	0	1/32 - 3/32
.0260	71	101	-----	-----	1/64 - 3/64
.0280	70	-----	00	-----	1/64 - 3/64
.0292	69	102	-----	-----	1/16 - 1/8
.0310	68	-----	-----	1	1/16 - 1/8
.0320	67	103	-----	-----	1/32 - 5/64
.0350	65	-----	0	-----	1/32 - 5/64
.0370	63	104	-----	-----	3/32 - 5/32
.0380	62	-----	-----	2	3/32 - 5/32
.0400	60	-----	1	-----	3/64 - 3/32
.0430	57	105	-----	-----	1/16 - 1/8
.0465	56	106	2	3	1/8 - 3/16
.0550	54	107	-----	4	5/32 - 7/32
.0595	53	-----	3	-----	1/8 - 3/16
.0635	52	108	-----	-----	1/8 - 3/16
.0670	51	-----	-----	5	3/16 - 5/16
.0730	49	109	4	-----	3/16 - 1/4
.0760	48	-----	-----	6	1/4 - 3/8

i. *Welding Hose.* Welding hose used in connecting the cylinders with the torch are specially made for this purpose. Oxygen hose is either green or black, and acetylene hose is red or maroon. The hose are attached to their respective regulators at one end and to the torch at the other. Acetylene hose fittings have left-hand threads and the nut is marked with a groove. Oxygen hose fittings have right-hand threads, and the nut is plain.

j. *Lighters.* A flint lighter is provided for igniting the torch. The lighter consists of a file-shaped piece of steel, usually recessed in a cup-like device, and a piece of flint that can be drawn across the steel, producing the sparks required to light the torch.

Caution: Matches should never be used to ignite a torch; their length requires bringing the hand too close to the tip in order to ignite the gas. Accumulated gas may envelope the hand and, when ignited, cause a severe burn.

k. *Goggles.* Welding goggles are fitted with colored lenses to keep out heat and light rays and to protect the eyes from sparks and molten metal. Regardless of the shade of lens used, it should be protected by a clear cover glass. The welding operator should select the shade or density of color that is best suited to him for his particular work. The desired lens is the one of the darkest shade which will show a clear definition of the work without eyestrain. Goggles should fit closely around the eyes and should be worn at all times during welding and cutting operations. Special goggles, utilizing standard lenses, are available for use with spectacles.

l. *Welding (Filler) Rods.*

(1) The use of the proper type filler rod is very important in oxyacetylene welding operations. This material not only adds reinforcement to the weld area, but also adds desired properties to the finished weld. By selecting the proper type rod, either tensile strength or ductility can be secured in a weld, or both can be secured to a reasonably high degree. Similarly, rods can be selected which will help retain the desired amount of corrosion resistance. In some cases, a suitable rod with a lower melting point will eliminate possible cracks from expansion and contraction.

(2) Welding rods may be classified as ferrous and nonferrous. The ferrous rods include carbon and alloy steel rods as well as cast iron rods. Nonferrous rods include brazing and bronze rods, aluminum and aluminum alloy rods, magnesium and magnesium alloy rods, copper rods, and silver rods.

(3) Welding rods are manufactured in

standard 36-inch lengths and in diameters from 1/16 inch to 3/8 inch. The diameter of rod used is governed by the thickness of the metals being joined. If the rod is too small, it will not conduct heat away from the puddle rapidly enough, and a burned weld will result. A rod that is too large will chill the puddle. As in selecting the proper size welding torch tip, experience will enable you to select the proper diameter welding rod.

191. Welding Flames

The welding flames are classified as neutral, oxidizing, or carburizing, each having its own special function. Adjustment of the torch enables the operator to produce the type of flame best suited for the job at hand. The neutral flame, in which a balanced mixture of oxygen and acetylene is burned, is used for most welding operations. The oxidizing flame, in which an excess of oxygen is burned, is used for welding bronze or fusing brass and bronze. The carburizing flame, in which an excess of acetylene is burned, is used when welding nickel alloys.

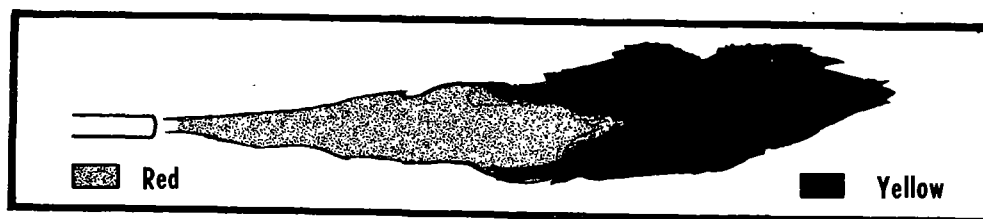
a. *Neutral Flame.*

(1) The neutral flame does not alter the composition of the base metal to any great extent and is therefore the best suited for most metals. The neutral flame burns at approximately 5,850°F. A balanced mixture of one volume of oxygen and one volume of acetylene is supplied from the torch when the flame is adjusted to neutral.

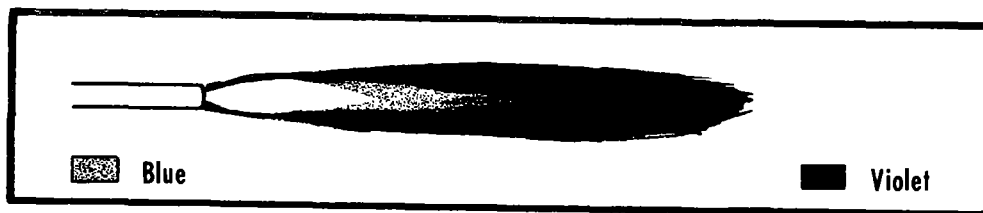
(2) As shown in figure 286, the neutral flame is divided into two distinct zones. The inner zone consists of the cone—a white, clearly defined, round, smooth cone, 1/16 to 3/4 inch in length. The outer zone, made up of completely burned oxygen and acetylene, is blue with a purple tinge at the point and edges.

(3) A neutral flame will not add to or take away from the properties of a metal when it melts. This type flame is of particular importance to the welder, because it is used for a wide variety of welding and cutting operations; and because it serves as a basis of reference in making other flame adjustments. Therefore, one of the first duties of a welder is to become familiar with the appearance and characteristics of the neutral flame.

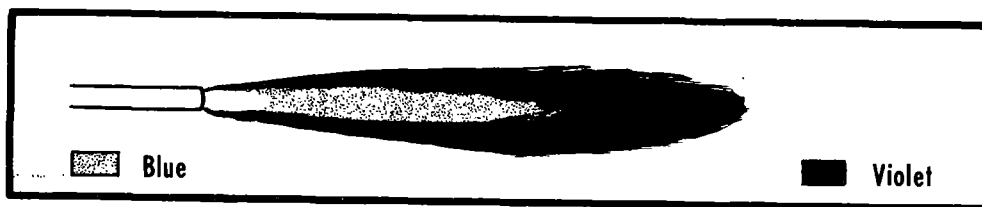
b. *Carburizing Flame.* The carburizing flame, produced by burning a greater volume of acetylene than oxygen, may be recognized by three different colors—a bluish-white inner cone, a white intermediate cone, and a light-blue outer flame (fig. 286). The degree of carburization can be determined by the length of the intermediate cone. The unburned carbon in the flame



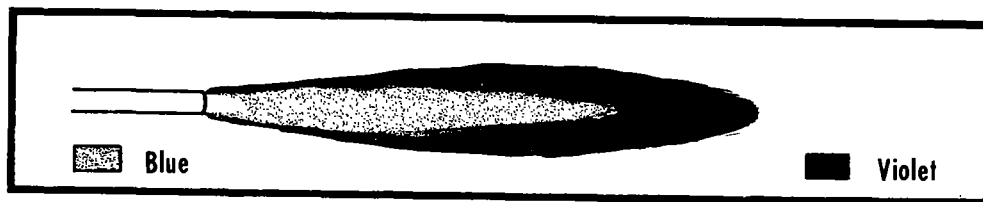
Acetylene burning in air - 1,500°F



Strongly Carburizing Flame - 5,700°F



Slight Excess Acetylene Flame - 5,800°F



Neutral Flame - 5,900°F



Oxidizing Flame - 6,300°F

Figure 286. Characteristics of the oxyacetylene flames.

is readily absorbed by the molten metal, producing a brittle, carburized surface.

c. Oxidizing Flame. The oxidizing flame is produced by burning a greater volume of oxygen than acetylene. It is similar in appearance to the neutral flame except the inner cone is shorter, more pointed, and has a purplish tinge (fig. 286). This flame can also be identified by a hissing sound. The oxidizing flame throws off numerous sparks when welding ferrous metal, and a foam or scum will form on the surface of the metal. This flame will burn the metal and cause it to be porous.

d. Flame Adjustment.

(1) To adjust the flame, light the torch by opening the torch acetylene valve 1/4 to 1/2 turn. With only the acetylene valve open, the flame will be yellow in color and will give off smoke and soot.

(2) Now open the torch oxygen valve slowly. The flame will gradually change in color from yellow to blue and will show the characteristic of the excess acetylene flame described earlier.

(3) With most torches, there will still be a slight excess of acetylene when the oxygen and acetylene valves are wide open and the rec-

ommended pressures are being used. Now close the acetylene valve on the torch very slowly. It will be noticed that the secondary cone gets smaller until it finally disappears completely. Just at this point of complete disappearance, the neutral flame is formed.

(4) In order to see the effect of an excess of oxygen, close the acetylene valve still further. A change will be noted, although it is by no means as sharply defined as that between the neutral and excess acetylene flames. The entire flame will decrease in size, and the inner cone will become much less sharply defined.

(5) Because of the difficulty in making a distinction between the excess oxygen and neutral flames, an adjustment of the flame to neutral should always be made from the excess acetylene side. Always adjust the flame first so that it shows the secondary cone characteristic of excess acetylene; then, increase the flow of oxygen until this secondary cone just disappears.

(6) During actual welding operations, where a neutral flame is essential, the flame should be checked occasionally to make certain it is neutral. This is accomplished by momentarily withdrawing the torch from the work and increasing the amount of acetylene until a distinctive feathery edge appears on the inner cone. Then, slowly decrease the amount of acetylene until a well-defined cone, characteristic of the neutral flame, is formed.

(7) With each size of tip, a neutral, oxidizing, or carburizing flame can be obtained. It is also possible to obtain a "harsh" or "soft" flame by increasing or decreasing the volume of both gases.

(8) When the gases are expelled from the torch tip at a relatively high velocity, the flame is called "harsh." For some work it is desirable to have a "soft" or low velocity flame without a reduction in thermal output. This may be achieved by using a larger tip and closing the gas needle valves until the neutral flame is quiet and steady. It is especially desirable to use a soft flame when welding aluminum, to avoid blowing holes in the metal when the puddle is formed.

e. Backfire and Flashback.

(1) Improper handling of the torch may cause the flame to backfire or, in very rare cases, to flashback. A backfire is a momentary backward flow of the gases at the torch tip causing the flame to go out. Sometimes the flame may immediately come on again, but a backfire is always accompanied by a snapping or popping noise. A backfire may be caused by touching the tip against the work, by overheating the tip, by operating the torch at other than recom-

mended pressures, by a loose tip or head, or by dirt or slag in the end of the tip. A backfire is rarely dangerous, but the molten metal may be splattered when the flame pops.

(2) A flashback is the burning of the gases within the torch and is dangerous. It is usually caused by loose connections, improper pressures, or overheating of the torch. A shrill hissing or squealing noise accompanies a flashback; and unless the gases are turned off immediately, the flame may burn back through the hose and regulators and cause great damage. The cause of a flashback should always be determined and the trouble remedied before relighting the torch.

f. Setting Up Equipment. Setting up welding equipment and preparing for welding must be done systematically and in a definite order to avoid costly mistakes. Follow the instructions listed below, in the order given, to assure your own safety and the safety of the equipment.

(1) Secure the cylinders so they cannot be upset. Remove the protecting caps from the cylinders, then the outlet connection caps.

(2) Crack the cylinder valves by opening each valve for an instant to blow it out clean. Close the valves and wipe off the connections with a clean cloth.

(3) Connect the acetylene pressure regulator to the acetylene cylinder and the oxygen regulator to the oxygen cylinder. Use a regulator wrench and tighten the connecting nuts tight enough to prevent leakage.

(4) Connect the red (or maroon) hose to the acetylene pressure regulator and the green (or black) hose to the oxygen regulator. Tighten the connecting nuts tight to prevent leaks. (Notice the left-hand threads on the acetylene hose connections. Do not force, as these threads are made of brass and are easily damaged.)

(5) Release both pressure regulator adjusting screws by turning the adjusting screw handle on each regulator counterclockwise until it runs free. (This is to avoid damage to the regulators and pressure gages when the cylinder valves are opened.)

(6) Open the cylinder valves slowly and read each of the cylinder pressure gages to check the contents in each cylinder.

Caution: Stand to one side of the regulator while opening a cylinder valve to avoid possible injury.

(7) Blow out each hose by turning the pressure adjusting screw handle inward (clockwise) and then turning it out again.

Caution: Acetylene hose should be blown out only in a well-ventilated space, free from sparks, flame, or other sources of ignition.

(8) Connect both hoses to the torch and check the connections for leaks by turning the pressure regulator screws in, with the torch needle valves closed. When 20 psi shows on the oxygen working pressure gage and 5 psi on the acetylene gage, close the valves by turning the pressure regulator screws out. A drop in pressure on the working gage indicates a leak between the regulator and torch tip. A general tightening of all connections should remedy the situation. If it becomes necessary to locate the leak, use the soapsuds method. Do this by painting all fittings and connections with a thick solution of soapy water.

Caution: Do not hunt for an acetylene leak with a flame as a serious explosion can occur in the hose or in the cylinder.

(9) Adjust the working pressure on both the oxygen and acetylene regulators by turning the pressure adjusting screw on the regulator clockwise until the desired settings are obtained.

(10) Light the torch, using the friction lighter provided. The torch is lighted by opening the acetylene needle valve and igniting the acetylene as it leaves the torch tip. Adjust the flame for the welding operation at hand, as described earlier.

Caution: When lighting the torch, always point the tip AWAY from your body, other persons, and flammable materials.

192. Shutting Down

Extinguish the torch flame by closing the acetylene needle valve first, then close the oxygen needle valve. When welding is stopped and will not be resumed within 15 minutes, or when the equipment is to be left unattended for any period of time, the equipment must be secured as follows:

- a. Extinguish the torch as described above.
- b. Close both acetylene and oxygen cylinder valves. (Leave regulators open momentarily.)
- c. Open acetylene valve on torch and allow gas to escape (5–15 seconds) to outside atmosphere. NOT into small or closed compartment. Close valve.
- d. Open oxygen valve on torch and allow gas to escape (5–10 seconds). Close valve.
- e. Close both regulators.

Note. Regulators are closed when adjusting screws are backed out (turned counterclockwise) until loose.

193. Fundamental Welding Techniques

a. Holding the Torch.

(1) The proper method to use in holding the torch depends upon the thickness of the metal being welded. For light-gage metal, hold the torch as shown in figure 287, with the hose

draped over the wrist. For heavier work, hold the torch as shown in figure 288.

(2) Hold the torch so that the tip is in line with the joint to be welded, and inclined between 30° and 60° from the perpendicular. The exact angle depends upon the type of weld to be made, the amount of preheating necessary, and the thickness and type of metal. The thicker the metal, the more nearly vertical the torch must be for proper heat penetration. The white cone of the flame should be held about 1/8 inch from the surface of the base metal.

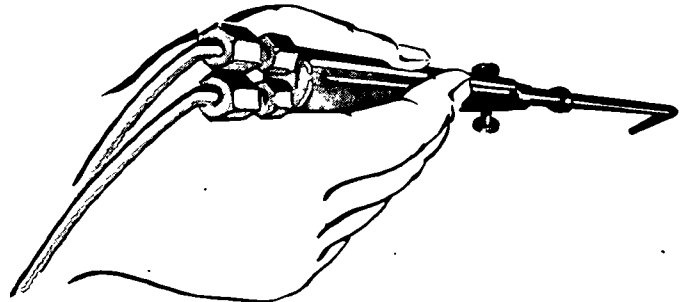


Figure 287. Welding light-gage metals.

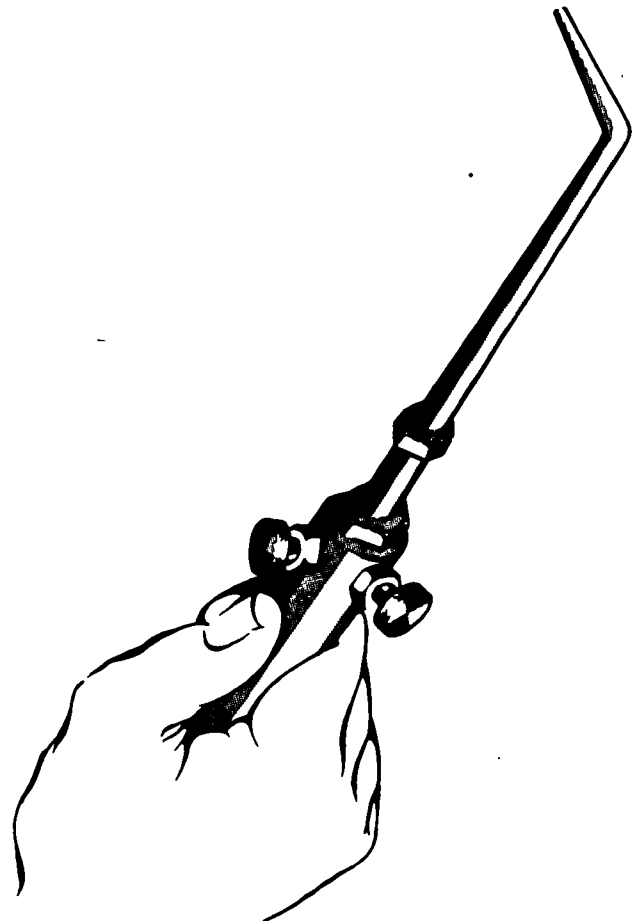


Figure 288. Welding heavy plate.

(3) If the torch is held in the correct position, a small puddle of molten metal will form. The puddle should be composed of equal parts of the two pieces being welded. After the puddle appears, begin the movement of the tip in a semi-circular or circular motion. This movement assures an even distribution of heat on both pieces of metal. The speed and motion of the torch are learned only by practice and experience.

b. *Forehand Welding.* Forehand welding is the technique of pointing the torch flame forward in the direction in which the weld is progressing. The filler rod is added to the puddle as the edges of the joint melt before the flame (fig. 289). The forehand method is used in welding most of the lighter tubings and sheet metals, or when the weld is to be made in certain positions.

c. *Backhand Welding.*

(1) Backhand welding is the technique of pointing the torch flame toward the finished weld and moving away in the direction of the unwelded area, melting the edges of the joint as it is moved (fig. 290). The welding rod is added to the puddle between the flame and the finished weld.

(2) Backhand welding is seldom used on sheet metal because the increased heat generated in this method is likely to cause overheating and burning. It is preferred for metals having a thick cross section. The large puddle of molten metal required for such welds is more easily controlled in backhand welding, and it is possible to examine the progress of the weld and determine if penetration is complete.

d. *Welding Positions.*

(1) The four basic welding positions are shown in figure 291. Also shown are four commonly used joints. Notice that the corner joint

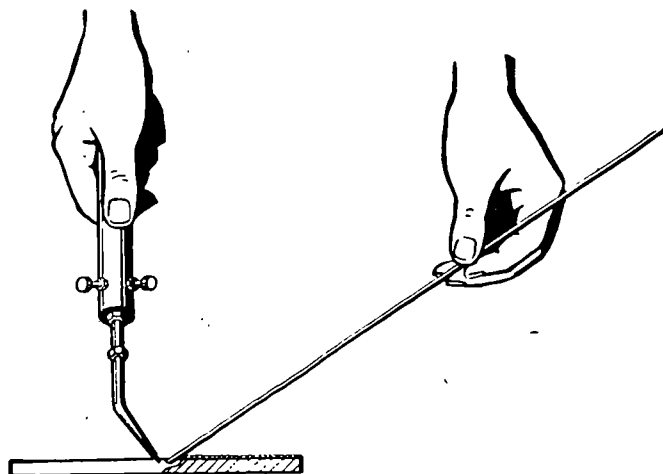


Figure 290. Backhand welding.

and butt joint are classified as groove welds, while the tee and lap joints are classified as fillet welds.

(2) Welding is always done in the flat position whenever possible. The puddle is much easier to control, and the welder can work longer periods without tiring. Quite often though, it is necessary to weld in the overhead, vertical or horizontal position in aircraft repair.

(3) The flat position is used when the material is to be laid flat or almost flat and welded on the topside. The welding torch is pointed downward toward the work. This weld may be made by either the forehand or backhand technique.

(4) The overhead position is used when the material is to be welded on the underside with the torch pointed upward toward the work. In welding overhead, the puddle can be kept from sagging if it is not permitted to get too large or assume the form of a large drop. The rod is used to control the molten puddle. The size of flame used should not be permitted to exceed that required to obtain a good fusion of the base metal with the filler rod. Less heat is required in an overhead weld because the heat naturally rises.

(5) The horizontal position is used when the line of the weld runs horizontal across a piece of work, and the torch is directed at the material in a horizontal or near horizontal position. The weld is made from right to left across the plate (for the right-hand welder). The flame is inclined upward at an angle of from 45° to 60°, and the weld is made with a normal forehand technique. Adding the rod to the top of the puddle will prevent the molten metal from sagging to the lower edge of the bead. If the puddle is to have the greatest possible cohesion, it should not be allowed to get too hot.

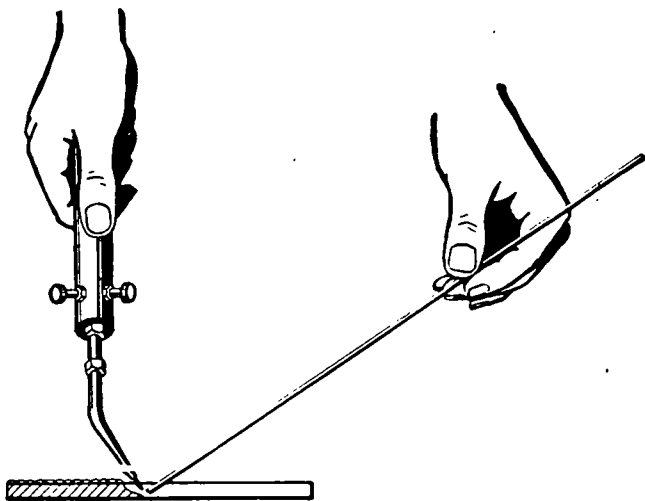


Figure 289. Forehand welding.

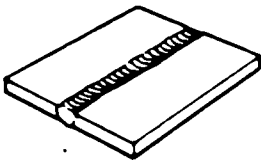
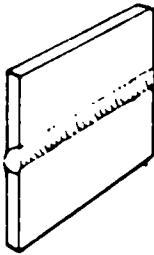
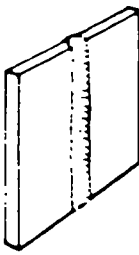
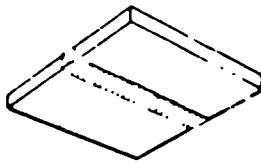
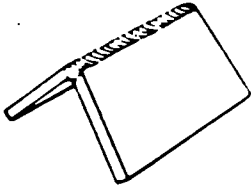
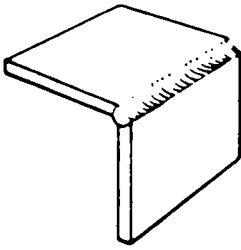
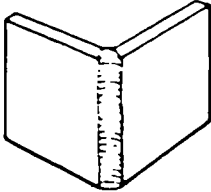
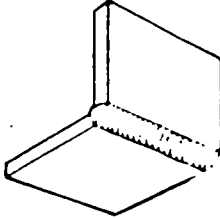
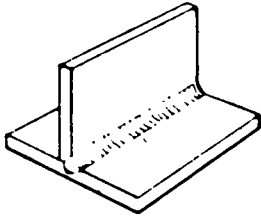
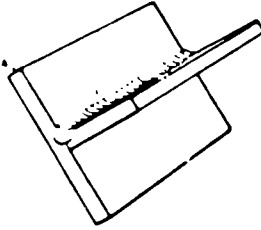
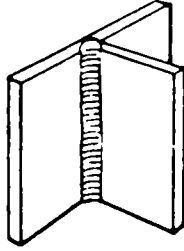
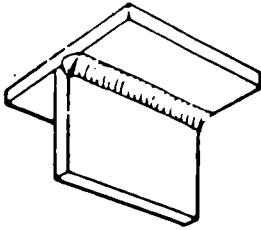
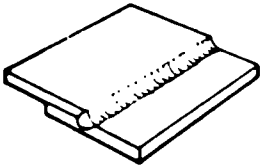
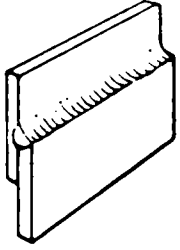
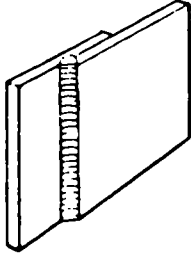
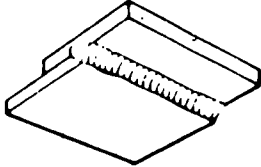
	FLAT	POSITION OF HORIZONTAL	WELDING VERTICAL	OVERHEAD
BUTT				
GROOVE CORNER				
TEE				
FILLET LAP				

Figure 291. Four basic welding positions.

(6) In a vertical weld, the pressure exerted by the torch flame must be relied upon to a great extent to support the puddle. It is highly important to keep the puddle from becoming too hot, in order to prevent the hot metal from running out of the puddle onto the finished weld. It may be necessary to remove the flame from the puddle for an instant to prevent overheating and then return it to the puddle. Vertical welds are begun at the bottom, and the puddle is carried upward with a forehand motion. The tip should be inclined from 45° to 60° , the exact angle de-

pending upon the desired balance between correct penetration and control of the puddle. The rod is added from the top and in front of the flame with a normal forehand technique.

194. Welded Joints

The five fundamental types of welded joints are the butt joint, tee joint, lap joint, corner joint, and edge joint (fig. 292).

a. Butt Joints.

(1) A butt joint is made by placing two pieces of material edge to edge, so that there is

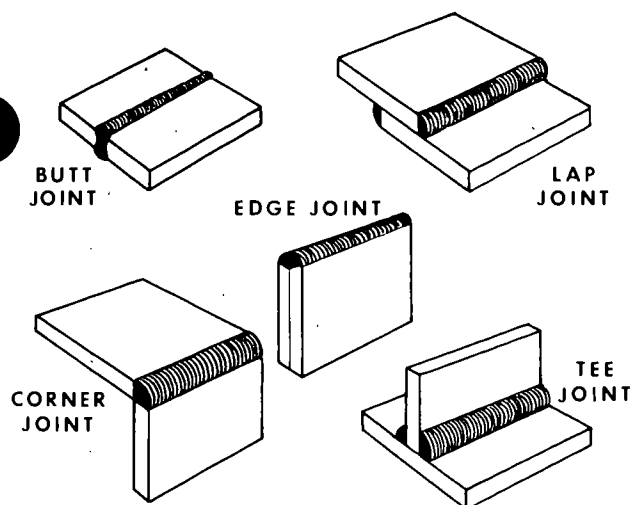


Figure 292. Types of welded joints.

no overlapping, and then welding. Some of the various types of butt joints are shown in figure 293. The flanged butt joint is used in welding thin sheets, 1/16 inch or less. The edges are prepared for welding by turning up a flange equal to the thickness of the metal. This type is usually made without the use of filler rod.

(2) A plain butt joint is used for metals from 1/16 to 1/8 inch in thickness. A filler rod is used in making this joint in order to obtain a strong weld.

(3) If the metal is thicker than 1/8 inch, it is necessary to bevel the edges so that the heat from the torch can penetrate completely through the metal. These bevels may be either single or double bevel type or single or double V-type. The U-type joint is generally used on very thick metals. A filler rod is used to add strength and reinforcement to the weld.

b. Lap Joints.

(1) The lap joint is seldom used in oxyacetylene welding of flat stock, but is commonly used in spot welding. The single fillet lap joint, shown in figure 294, has very little resistance to bending, and will not withstand the shearing stress to which the weld is subjected under tension or compression loads.

(2) The double fillet lap joint, also shown in figure 294, offers more strength, but requires twice the amount of welding required on the simpler, more efficient butt weld.

c. Tee Joints. A tee joint is formed when the edge or end of one piece is welded to the surface of another, as shown in figure 295. These joints are quite common in aircraft work, particularly in tubular structures. The plain tee joint is suitable for most aircraft metal thicknesses but heavier metals require the vertical member to

be single or double beveled, in order to permit the heat to penetrate deeply enough. The dark areas in the illustrations show the depth of a heat penetration and fusion required.

d. Edge Joints. An edge joint may be used when two pieces of sheet metal must be fastened together and load stresses are not important. Edge joints are usually made by bending the edges of one or both parts upward, placing the two bent ends parallel to each other or placing one bent and parallel to the upright unbent end, and welding along the outside of the seam formed by the two jointed edges. Figure 296 shows two types of edge joints. The type shown in (A) requires no filler rod, since the edges can be melted down to fill the seam. The type shown in (B), being thicker metal, must be beveled for heat penetration and filler rod added for reinforcement.

e. Corner Joints.

(1) A corner joint is made when two pieces of metal are brought together so that their edges form a corner of a box or inclosure as shown in figure 297.

(2) The corner joint shown in (A) requires little or no filler rod, since the edges fuse to make the weld. It is used where load stress is unimportant. The joint shown in (B) is used on heavier metals, and filler rod is added for roundness and strength. If much stress is to be placed on the corner, the inside is reinforced as shown in (C).

195. Melting Point

The melting point of any substance is the temperature at which the solid substance becomes liquid. Pure metals have a constant melting point; but when alloyed with other metals or chemicals, the melting point is changed. The amount of the change depends upon the percentage and melting point of the alloying elements. As a welder, you should know the approximate melting points of the various metals because it is often necessary to weld together metals which differ in this respect. Table 51 shows the melting point of the most commonly used aircraft metals.

196. Expansion and Contraction

a. Heat causes metals to expand; cooling causes them to contract. Uneven heating will, therefore, cause uneven expansion, or uneven cooling will cause uneven contraction. Under such conditions, stresses are set up within the metal. These forces must be relieved; and unless precautions are taken, warping or buckling of the metal takes place. Likewise, on cooling, if nothing is done to take up the stress set up by

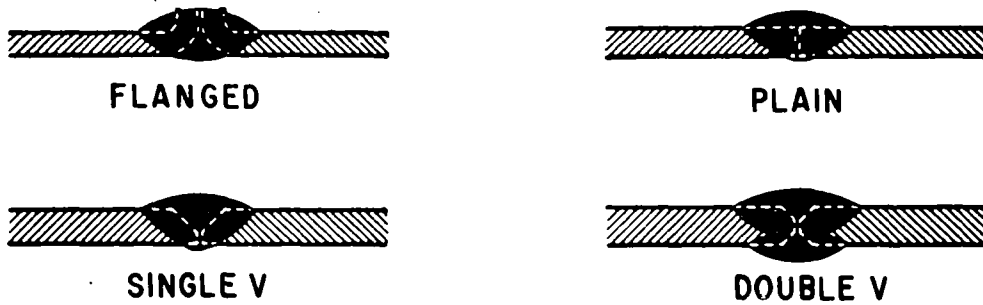


Figure 293. Types of butt joints.



Figure 294. Single and double fillet lap joints.

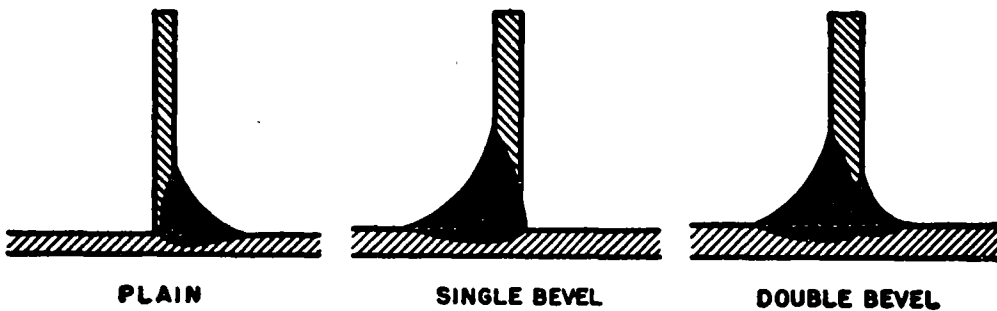


Figure 295. Types of tee joints.

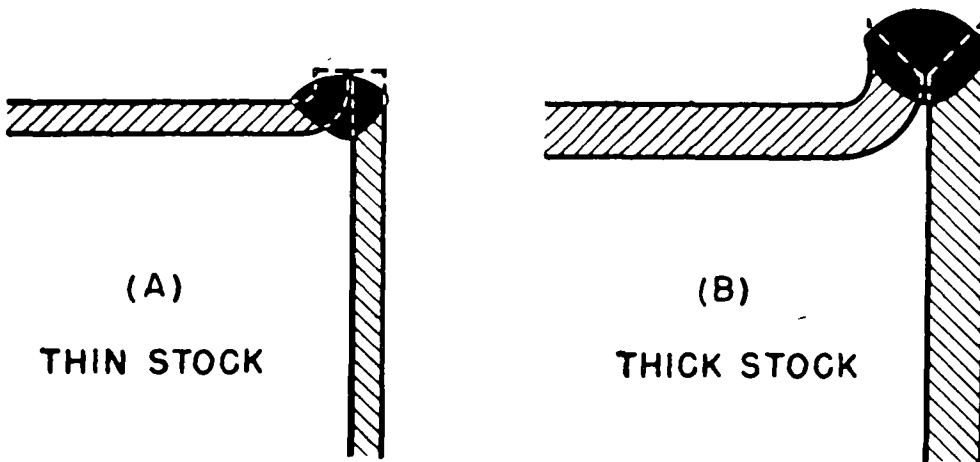


Figure 296. Types of edge joints.

the contraction forces, further warping may result; or if the surrounding cool sections of the metal are too heavy to permit this change in shape, the stresses remain within the metal itself. Such stresses may cause cracking while cooling, or may remain within the metal until further force is applied, as when the piece is put into use.

b. Sheet metal ($1/8$ inch and less in thickness) has such a large surface area per unit of weight, heat stresses tend to produce warping or buckling of the sheet. This and the contraction effect encountered on long seams are the main points to be considered in sheet metal welding.

c. The effect of welding a long seam (over 10 or 12 inches) is to draw the seam together as the

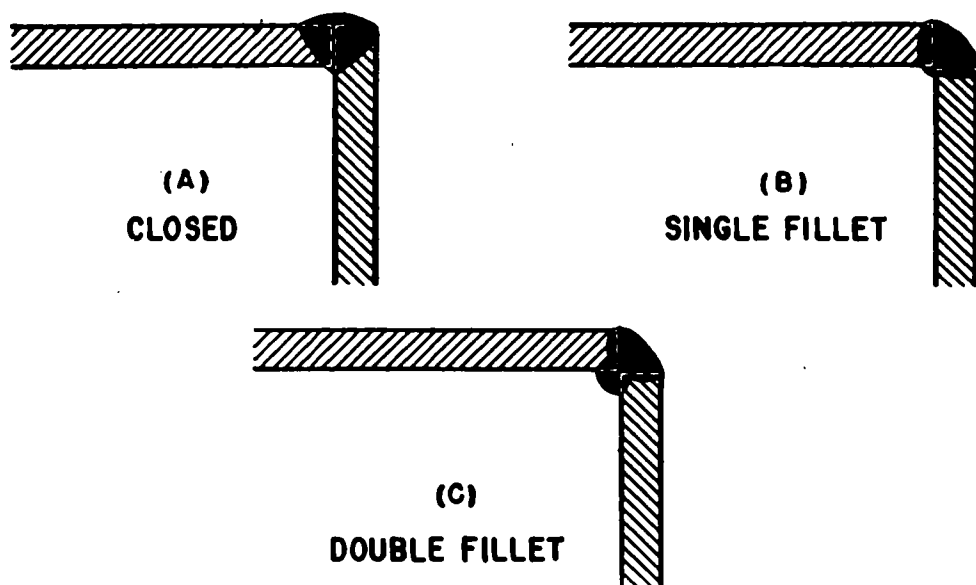


Figure 297. Types of corner joints.

weld progresses. If the edges of the seam are placed in contact with each other throughout

Table 51. Melting Points of Aircraft Metals

Metal	Melting point (degrees F.)
Aluminum, case, 8 per- cent copper	1,175
Aluminum, pure	1,220
Aluminum, 5 percent silicon	1,117
Bismuth	520
Brass	1,660
Bronze	1,598
Chromium	2,740
Copper	1,981
Inconel	2,540
Iron, cast	2,300
Iron, Malleable	2,300
Iron, wrought	2,900
Lead	620
Magnesium	1,202
Molybdenum	4,532
Nickel	2,646
Silver	1,762
Steel, high carbon	2,500
Steel, low carbon	2,700
Steel, medium carbon	2,600
Steel, manganese	2,450
Steel, nickel	2,600
Steel, cast	2,600
Stainless steel	2,650
Tin	450
Titanium	3,100
Vanadium	3,182
Zinc, cast or rolled	786

their length before welding starts, the far ends of the seam will actually overlap before the weld is completed.

d. One way of overcoming this effect is illustrated in figure 298. The two pieces to be welded are placed with an increased allowance at the far end; and as the welding progresses, the two pieces are drawn together. This allowance is generally one metal thickness per foot of seam.

e. Another method of controlling expansion and contraction is by the use of chill bars. Heavy pieces of metal are placed on either side of the weld; they absorb the heat and keep it from spreading across the whole surface area. Copper is commonly used for chill bars because of its ability to absorb heat readily. Welding jigs sometimes use this same principle to remove heat from the base metal (fig. 299).

f. Preheating is another method of controlling expansion and contraction. Preheating is especially important in welding tubular structures and also in welding castings. Contraction still takes place at the weld, but there is also shrinking in the rest of the structure at approximately the same rate.

197. Characteristics of a Good Weld

A completed weld should have the following characteristics:

a. The bead should be smooth, the bead ripples evenly spaced, and of a uniform thickness.

b. The weld should be built up, thus providing extra thickness at the joint.

c. The weld should taper off smoothly into the base metal.

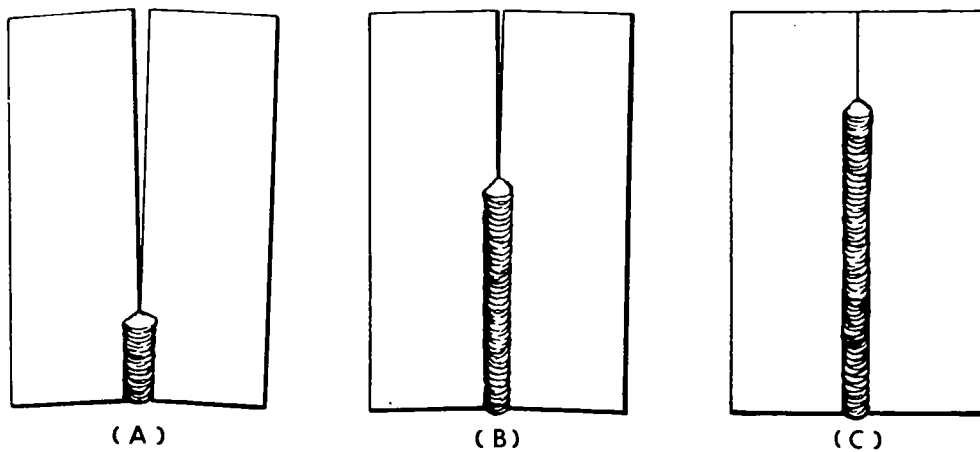


Figure 298. Allowance for a straight butt weld.

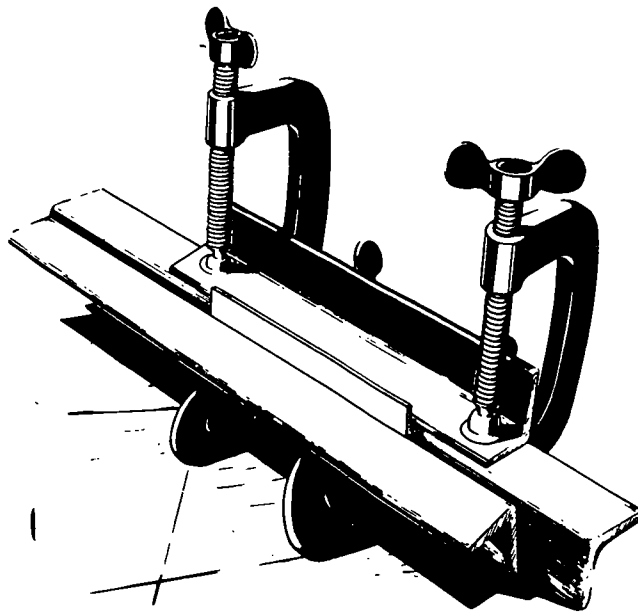


Figure 299. Example of the use of jigs and chill bars.

d. No oxide should be formed on the base metal close to the weld.

e. The weld should show no signs of blow-holes, porousness, or projecting globules.

f. The base metal should show no signs of burns, pits, cracks, or distortion.

g. Although a clean, smooth weld is desirable, this characteristic does not necessarily mean that the weld is a good one; it may be dangerously weak inside. However, when a weld is rough, uneven, and pitted, it is almost always unsatisfactory inside. Welds should never be filed to give them a better appearance, since filing deprives the weld of part of its strength. Nor should they be filed with solder, brazing material, or filler of any sort.

h. When it is necessary to reweld a joint, all old weld material must be removed before the

operation is begun. It must be remembered though, that reheating the area causes the base metal to lose its strength and become brittle.

198. Welding Ferrous Metals

Low-carbon steel, low-alloy steel, cast steel, and wrought iron are easily welded with the oxyacetylene flame. Plain, low-carbon steel is the ferrous material that will be gas welded most frequently. As the carbon content of steel increases, welding becomes more difficult. For this reason aircraft parts made of steel may be repaired by welding only under certain conditions. For corrosion and heat resistant nickel-chromium steels, the allowed weldability depends upon their stability, carbon content, or reheat treatment. Before attempting a repair which includes the welding of aircraft steels, the appropriate military specification should be consulted.

a. Preparation for Welding.

(1) Proper preparation for welding is an important factor in every welding operation. The edges of the parts must be prepared in accordance with the joint design chosen. The edges must be CLEAN. Arrangements must be made for holding the parts in proper alignment and for preheating, if this is required.

(2) The first step in preparing an aircraft part for welding is to strip it of all dirt, grease or oil, and any protective coating such as cadmium plating, enamel, paint, or varnish. Such coatings not only hamper welding, but also mingle with the weld to prevent good fusion. Cadmium plating can be chemically removed by dipping the edges to be welded in a mixture of 1 pound of ammonium nitrate and 1 gallon of water.

(3) Paint or varnish may be removed with a wire brush or emery cloth, by sandblasting, by using paint or varnish remover, or by treating the pieces with a 10 percent caustic soda solution followed by a thorough washing with hot water to remove solvent or residue.

(4) Sandblasting is the most effective method for removing rust or scale from steel parts. Grease or oil may be removed with a suitable grease solvent.

b. Welding Techniques.

(1) Carbon steels. In general, the carbon steels that are weldable require no preheating, and no flux is required. Use a low-carbon steel filler rod containing a small percentage of vanadium. Carefully adjust the torch flame to neutral.

(2) Use the forehand method holding the torch at an angle of 60° to the surface of the work. Be sure that the tip of the inner cone of the flame does not quite touch the molten metal. If the edges of the metal have been beveled, use a swinging motion of the torch to melt the metal on each side of the groove.

(3) While heating both sides of the groove, hold the filler rod in the outer cone of the flame to heat it. The filler rod should almost reach the melting point by the time that the puddle of molten metal has formed in the bottom of the groove.

(4) As the torch and rod are moved in the same direction, dip the rod at approximately a 45° angle. Dip the tip of the filler rod below the surface of the weld puddle just before the rod begins to melt, and move it from side to side in the puddle with a motion exactly opposite to the motion of the torch. If the filler rod is held above the surface of the puddle, it will melt and

fall into the puddle a drop at a time. This ruins the weld.

(5) Add filler metal until the surface of the joint is built up slightly above the edges of the parts being joined. Gradually advance the puddle of molten metal along the seam until the end is reached.

(6) As the end of the seam is approached, raise the torch slightly, chilling the molten steel to prevent it from spilling over the edge and/or melting through the work.

c. Chrome-Molybdenum Steel.

(1) The welding technique for chrome-molybdenum is practically the same as that for carbon steels, except that the surrounding area must be preheated to a temperature between 300° and 400° F before beginning to weld. To preheat the metal, direct the flame at such an angle that preheating takes place just ahead of the weld. Use a rod of the same material as the base metal. Use a soft neutral to slightly carburizing flame just large enough to melt the base metal and to obtain good fusion.

(2) If jigs or fixtures are used, they should be designed to prevent any strains from contraction while the metal is cooling. In other words, the metal should not be clamped too tight.

(3) Chrome-molybdenum thicker than 0.093 inch should be electric arc welded. In electric arc welding, the heat zone is narrower, the heat strains are lower, and a better weld will be obtained.

d. Stainless Steel.

(1) The procedure for welding stainless steel is basically the same as that for carbon steels. There are, however, some special precautions that must be taken in order to obtain the best results.

(2) Only stainless steel used for nonstructural members of aircraft can be welded satisfactorily; the stainless steel used for structural components is cold-worked or cold-rolled and if heated, loses some of its strength. Nonstructural stainless steel is obtained in sheet and tubing form and is often used for exhaust collectors, stacks, or manifolds. Oxygen combines very readily with this metal in the molten state, and extreme care must be taken to prevent this combination.

(3) A slightly carburizing flame is recommended for welding stainless steel, and the welder should adjust the flame so that a feather of excess acetylene, about 1/16 inch long, forms around the inner cone. Too much acetylene, however, will add carbon to the metal and cause it to lose its resistance to corrosion. The torch tip size should be one or two sizes smaller than that

prescribed for a similar gage of plain steel. The smaller tip lessens the chances for overheating and subsequent loss of the "stainless" qualities of the metal.

(4) Thin sheets which are to be butt welded should be tacked at intervals of 1 1/4 to 1 1/2 inches, as shown in figure 300. This is one means of lessening warping and distortion during the welding process.

(5) Stainless steel must be protected from the atmosphere to prevent the nitrogen and oxygen in the air from combining with the hot metal. This is done by welding in an atmosphere of inert gas, or by using a suitable flux. Flux for gas welding of corrosion-resistant or heat-resistant alloys must conform to the requirements of Specification MIL-F-7516B. Fluxes must not increase the carbon content of the weld metal significantly.

(6) The flux used with stainless steel is compounded especially to dissolve the chromium oxide which forms on the molten metal. It is mixed with water until it forms a thin paste. Apply the flux to the underside of the seam and to the filler rod. Allow the flux to dry a few minutes after brushing it on.

(7) If the pieces to be welded are thinner than 0.063 inch, turn up flanges on each edge to a height equal to the metal thickness. The flanges will melt down and furnish enough metal to fill the seam.

(8) For stainless steel from 0.063 to 0.093 inch thick, use a plain butt joint and place a backing strip of copper beneath the seam to prevent the molten metal from flowing out of the weld and to absorb some of the heat. Use a filler rod of the same material as the base metal.

(9) Stainless steel thicker than 0.093 inch should be electric arc welded if possible; but if it must be oxyacetylene welded, bevel the edges to form a V-type butt joint.

199. Welding Nonferrous Metals

a. Aluminum Alloys.

(1) Gas welding of aluminum alloy is usually confined to materials from 0.031 to 0.125 inch in thickness. Thicker material may be gas welded if necessary, but thinner material is usually spot or seam welded.

(2) Aluminum alloys best suited for gas welding are 1100, 3003, 5052, 6056, 6061, and 6063. Gas welding of 2014, 2017, 2024, and 7075 is not recommended since the strength of the metal in the vicinity of the weld is lowered considerably and cannot be restored. Corrosion resistance is also seriously impaired.

b. Melting Characteristics of Aluminum.

(1) Before attempting to weld aluminum alloy for the first time, it is advisable to become familiar with the action of the metal under the welding flame.

(2) Place a small piece of sheet aluminum on the welding table, light the torch, and adjust the flame to neutral. With the flame held perpendicular to the surface of the sheet, bring the tip of the inner cone almost in contact with the metal. Observe that almost without warning the metal suddenly melts and runs away leaving a hole in the sheet. Now repeat the operation with the torch held at an angle of about 30° to the plane of the surface. With a little practice, you will be able to melt the surface metal without forming a hole. Now try moving the flame slowly along the surface of the sheet, melting a small puddle. Observe how quickly the puddle solidifies when the flame is removed. Continue this practice until able to control melting, then proceed with practice in actual welding, starting with simple flanged and notched butt joints which do not require welding rod. Then proceed with the use of welding rod, at first with thin sheet and subsequently with castings.

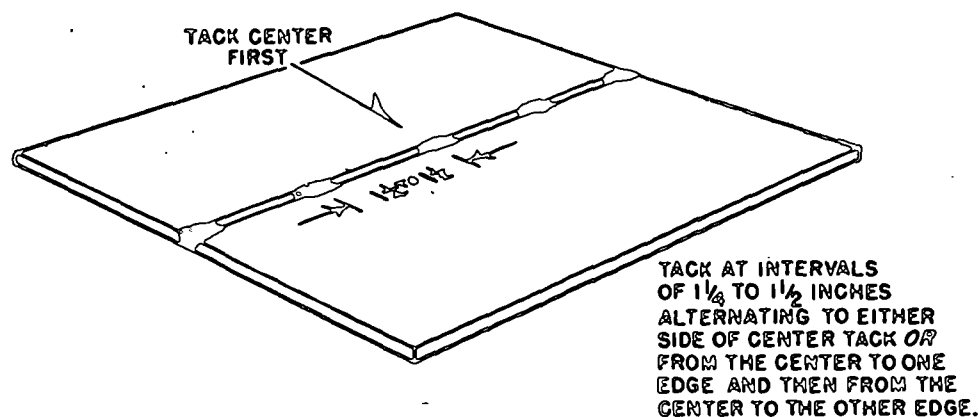


Figure 300. Tacking methods.

c. Preparation of Aluminum for Welding.

(1) Thickness of the material determines the method of edge preparation. On material up to 0.062 inch, the edges should be formed to a 90° flange about the same height as the thickness of the material or higher. (See (A) of fig. 301.) The only requirement for the flanges is that the edges be straight and square. If desired, material up to 0.125 inch may be welded with a flange type joint. No filler rod is necessary when the edges are flanged.

(2) Unbeveled butt welds may be made on thicknesses from 0.062 to 0.188 inch, but in these applications it is necessary to notch the edges with a saw or cold chisel in a manner similar to that shown in (B) of figure 301. Edge notching is recommended in aluminum welding because it aids in getting full penetration and also prevents local distortion. All butt welds in material over 0.125 inch thick are generally notched in some manner.

(3) In welding aluminum over 0.188 inch thick, bevel the edges and notch them as shown in (C) of figure 301. The included angle of bevel may be from 90° to 120°.

(4) After the edges of the pieces have been properly prepared, the surfaces to be welded should be cleaned. If heavy oxide is present on the metal surface, it may be necessary to use a stainless steel wire brush. A solvent-soaked rag will remove dirt, grease, or oil.

(5) Preheating—aluminum plate 1/4 inch thick and over should be preheated in order to prevent cracks and to assure more complete penetration. Thin materials should be warmed with the torch prior to welding; even this slight preheat helps to prevent cracks.

(6) Welding rods—two types of welding rods are available for gas welding aluminum alloys; they are the 1100 and 4043 rods. The 1100 rod is used when maximum resistance to corrosion and high ductility are of prime importance. The 1100 rod is used for welding 1100 and 3003 only. The 4043 rod is used for greater strength and to minimize the tendency for cracking. It is used for all other wrought aluminum alloys and may be used for castings.

(7) Welding fluxes—the use of the proper flux in welding aluminum is extremely important. Aluminum welding flux is designed to remove the aluminum oxide by chemically combining with it. In gas welding, the oxide forms rapidly in the molten metal. It must be removed or a defective weld will result. To insure proper distribution of the flux, it should be brushed on the surface to be welded and also applied to the welding rod.

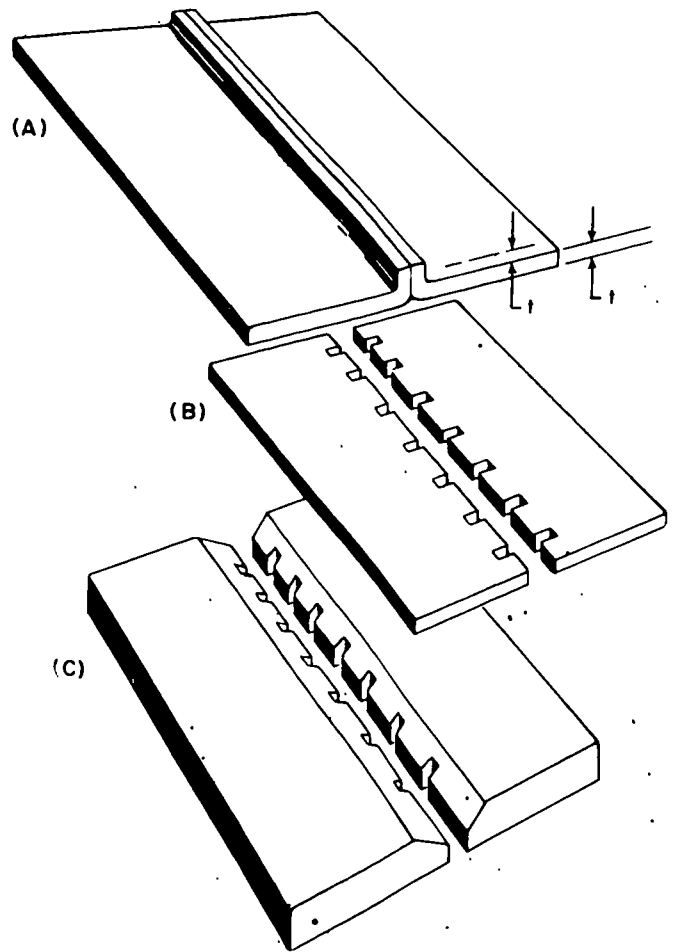


Figure 301. Edge preparation for gas welding aluminum.

(8) Aluminum flux is generally obtained in powder form, and it should conform to specification MIL-F-6939A. It is best prepared for use by mixing the powder with water to form a paste. The paste should be kept in an aluminum, glass, or earthen ware container, since steel or copper containers tend to contaminate the mixture.

(9) It is particularly essential that plenty of flux be applied to the edges of flanged joints since no filler rod is used in these joints. In all cases, the flux should be applied to both the bottom and top sides of the sheet in the area of the weld.

(10) After welding is finished, it is important that all traces of flux be removed by using a brush and hot water. If aluminum flux is left on the weld, it will corrode the metal.

d. Welding Technique for Aluminum.

(1) After the pieces to be welded have been properly prepared and fluxed, pass the flame in small circles over the starting point until the flux melts. Then scrape the rod over the surface at about 3- or 4-second intervals, permitting the

rod to come clear of the flame each time, otherwise the rod will melt before the parent metal, and it will be difficult to note when the welding should start. The scraping action will reveal when welding can be started without overheating the aluminum. Maintain the same cycle throughout the course of welding except for allowing the rod to remain under the flame long enough to melt the amount of metal needed. The movement of the rod can easily be mastered with practice.

(2) Forehand welding is generally considered best for the welding of aluminum alloys since the flame points away from the completed weld and thus preheats the edges to be welded. Too rapid melting is also prevented. Hold the torch at a low angle when welding thin material (less than 30° above horizontal). For thicknesses 0.188 inch and above, increase the angle of the torch to nearer vertical. Changing the angle of the torch in accordance with the thickness of the metal minimizes the possibility of burning through the sheet during welding.

(3) In welding aluminum alloys up to 0.188 inch thick, there is little need to impart any motion to the torch other than moving it forward. On flanged material, care must be taken to break the oxide film as the flange melts down. This may be accomplished by stirring the melted flange with a puddling rod, illustrated in figure 302. (A puddling rod is essentially a paddle flattened and shaped from a 1/4-inch stainless steel welding rod.)

(4) With aluminum alloys above 0.188 inch in thickness, the torch should be given a more uniform lateral motion to distribute the weld metal over the entire width of the weld. A slight back-and-forth motion will assist the flux in its removal of oxides. Dip the rod in the weld puddle periodically and withdraw it from the puddle with a forward motion.

(5) The angle of the torch has much to do with welding speed. Instead of lifting the flame from time to time in order to avoid melting holes in the metal, it will be found advantageous to hold the torch at a flatter angle to the work.

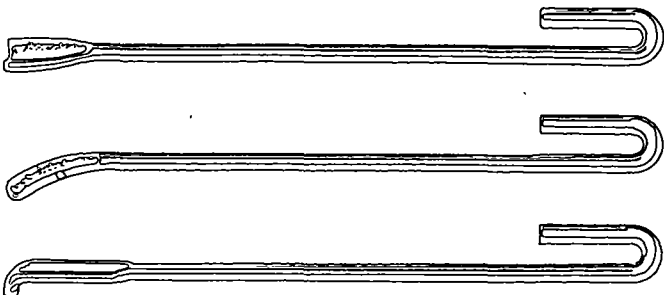


Figure 302. Puddling rods.

The speed of welding should be increased as the edge of the sheet is approached. The inner cone of the flame should never be permitted to come in contact with the molten metal, but should be held about 1/8 inch away from the metal.

(6) In the vertical position, the torch is given an up-and-down rather than a rotating motion. In the overhead position, a light back-and-forth motion is employed the same as in flat welding.

(7) Heat-treatable alloys should be held in a jig for welding, whenever possible. This helps to eliminate the possibility of cracking. The likelihood of cracking can also be reduced by the use of 4043 rod. This rod has a lower melting range than the alloy being joined and so permits the base metal to solidify before the weld puddle freezes. As the weld is the last area to solidify, all the contraction strains will be in the weld bead rather than throughout the base metal.

(8) Cracking may also be reduced by tack welding the parts while they are in the jig and then loosening the clamps before completing the seam.

(9) As soon as the weld is completed and the work has had time to cool, it should be washed thoroughly by vigorous scrubbing with a stiff brush and hot running water to remove all traces of flux. If left on the weld, it will corrode the metal. A diluted solution of 10 percent sulfuric acid may be used if hot water is not available. The acid solution should be washed off with cold fresh water after using.

e. Magnesium Alloys.

(1) Gas welding was once a widely used method of joining magnesium alloys; but because of corrosion difficulties caused by flux, its principal use at present is for emergency repair work or for welding on extremely thin gage sheet. Magnesium alloy parts used as structural members on aircraft cannot be repaired by gas welding since these parts are heat treated and it is impossible to regain the required strength after welding.

(2) Nonstructural magnesium parts which have been broken or cracked usually can be sufficiently repaired by gas welding to enable the part to be placed back in service. Generally speaking, such a repair should be considered only as a temporary measure until a replacement part can be obtained. This is particularly true in the case of repairs made on magnesium castings.

(3) The emergency welding of magnesium parts often requires deviation from good practice in order that the parts may be placed back in service quickly. Examples of such deviation are the use of multiple bead welds, the welding

of sections that are impossible to clean thoroughly, the gas welding of cast metal, and the inadequate cleaning of welds due to lack of facilities.

(4) Because the flux is very corrosive, gas welding is restricted almost entirely to simple butt and corner welds where complete flux removal is possible after welding. For this reason, gas welding has been almost entirely supplanted by the inert-gas shielded arc welding process. However, gas welding does possess the advantages of less fit-up and jiggling requirements, and can be done by less highly skilled operators than inert-gas arc welding requires.

(5) The strength properties of gas welds in magnesium sheet are usually lower than those of inert-gas arc welds. Corrosion resistance of gas welds equals that of inert-gas arc welds, provided all traces of flux have been removed.

(6) Welding fluxes for magnesium are supplied in dry powder form in glass jars which must be kept tightly closed when not in use. It is made into a paste by mixing one part water to two parts of flux. Only enough flux paste for one day's use is mixed at one time and the paste, too, is kept in covered glass containers when not being used.

f. Preparation of Magnesium for Welding.

(1) Sheet magnesium alloy up to 0.040 inch in thickness should be flanged by about $\frac{3}{32}$ inch to the angle as indicated in figure 303. Butt joints on metal from 0.040 to 0.125 inch in thickness are neither flanged nor beveled, but a space of $\frac{1}{16}$ inch should be allowed between the edges of the joint. For butt joints in metal thicker than 0.125 inch, bevel down each edge 45° to make a 90° included angle for the V. Allow $\frac{1}{16}$ inch space between the edges of the joint for metal 0.125 to 0.250 inch thick and $\frac{1}{8}$ inch space for metal 0.250 inch and up (fig. 303).

(2) Remove oil or grease with a suitable solvent, then use a wire brush or abrasive cloth

to clean and brighten the edges of the joint. Select a filler rod of the same material as the base metal. The filler rod and both sides of the seam should be covered with flux. A neutral or slightly carburizing flame should be used, and it should be held at a flat angle to the work to avoid burning through.

g. Welding Technique for Magnesium.

(1) Start the weld by tacking the seam at intervals of $\frac{1}{2}$ to $1\frac{1}{2}$ inches. If the sheet warps while tack welding, it can be straightened with a wooden or plastic mallet.

(2) After tack welding, coat the tacks with flux and then weld completely a piece of the seam from 1 to 2 inches long at each end. This reduces the tendency of the metal to warp while the weld is being made. Shrink cracks at the end of the seam can be eliminated by adding an excess of weld metal at that point. Use as little heat as possible.

(3) Each of the two major producers of magnesium recommends a different technique for welding magnesium. One prefers keeping the filler rod in the molten pool of metal, which means getting enough flux on the rod before starting the weld so that the rod will not be taken out of the puddle to renew the flux. The other producer recommends the same torch and rod technique for magnesium as used for aluminum. Use the method with which you can attain the greater success.

(4) If any part of the weld begins to oxidize, carefully scrape out the oxidized portion of the weld before continuing the operation.

(5) Upon completing the weld, let it cool slowly. When cool enough to handle, scrub the accessible parts lightly to remove most of the flux. Then put the part in hot water and soak off the large particles of flux adhering to any inner parts of the weld which scrubbing does not affect.

(6) Take the part out of the hot water and soak it for 10 minutes in a 1 percent citric acid solution. Gas bubbling from the vicinity of the weld will loosen the flux particles. If the part is made so that gas cannot escape readily, rock or turn it frequently to prevent formation of gas pockets where the flux may not be completely removed.

(7) Upon removing the part from the citric acid solution, drain it thoroughly and rinse clean in cold water.

200. Cutting Ferrous Metals

There are numerous everyday uses for oxyacetylene flame cutting. It is a quick, inexpensive way to cut iron or steel where the effect of burning or heating the edge of a piece of metal is not

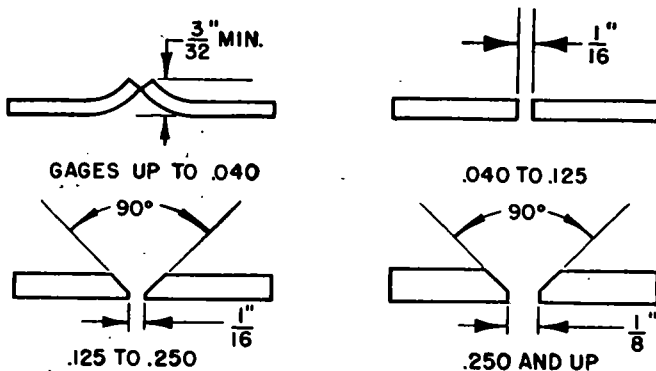


Figure 303. Preparation of edges for welding magnesium sheet.

objectionable. While the cutting of metals with an oxyacetylene torch is not done on aircraft, it has many uses in general work around the shop. Ferrous metals combine with oxygen so readily that the oxygen in the air can start the reaction, as rusty pieces of iron in scrap piles will attest. The rust is iron oxide, and the longer a piece is exposed to the elements, the more it is worn away and the more rust it collects.

Cutting iron or steel with an oxyacetylene torch is simply a speeding up of this process in a localized area, because iron oxidizes much more readily when it is hot. Pure oxygen, if directed on a hot piece of iron, increases the rate of oxidation so enormously that the metal is actually burned away. The metal is heated to a bright red (1,400° to 1,600° F), which is the kindling or ignition temperatures, and a jet of high-pressure oxygen is directed against it. This oxygen blast combines with the hot metal and forms an intensely hot oxide. The molten oxide is blown down the sides of the cut, heating the metal in its path to a kindling temperature. The metal thus heated also burns to an oxide which is blown away on the underside of the piece. This action is precisely that which the torch accomplishes when the mixing head is replaced with a cutting attachment or when a special cutting torch is used. Figure 304 shows an example of a cutting torch. It has the conventional oxygen and acetylene needle valves, which control the flow of the two gases. Many cutting torches have two oxygen needle valves so a finer adjustment of the neutral flame can be obtained. A cutting torch combines a heating flame with a jet of pure oxygen under pressure. The heating flame preheats the metal to a bright red, and the oxygen jet is directed upon the hot metal to burn it away and thus form a slit, known as a kerf, in the metal. The heating flame in a cutting tip is generally not fed by a single hole as in a welding tip, but instead comes through several holes which are arranged in a ring around a larger central hole for oxygen (fig. 304). The central oxygen tube tapers as it reaches the tip opening to increase the velocity. The high-pressure cutting oxygen jet is regulated by an auxiliary oxygen control valve generally operated by a lever. This is shown in figure 304. Four different size tips are generally supplied for cutting metals of varying thicknesses. There are also special tips for cleaning metal; cutting rusty, scaly, or painted surfaces; rivet cutting; and other special jobs. In cutting, as in welding, the pressure of oxygen and acetylene and the size of tip are determined by the thickness and quality of the metal to be cut. Table 52 shows the approximate pressures for various size tips.

Table 52. Approximate Pressure for Various Tip Sizes

Tip No.	Thickness of metal (inches)	Acetylene pressure (pounds)	Oxygen pressure (pounds)
1	1/8	4	10
1	1/4	4	15
1	3/8	4	20
1	1/2	4	25
2	3/4	5	30
2	1	5	40
2	1 1/2	5	50
2	2	5	60
3	3	6	70
3	4	6	80
3	5	6	90
4	6	7	100
4	8	7	130
4	10	8	160

a. Cutting Procedure.

(1) Before beginning a cutting operation with an oxyacetylene cutting torch, a thorough inspection of the area should be made. There should be no combustible material which could be ignited by the sparks and slag produced by the cutting operation.

(2) Insert the proper size tip in the cutting torch. Next, adjust the oxygen and acetylene pressures for the thickness of material to be cut. (The tip size and pressures should be in accordance with the cutting torch manufacturer's recommendations.) Put on goggles and gloves then light the torch.

(3) To light the torch, turn on the acetylene needle valve, light the gas, and adjust the flame to neutral as in welding. When the neutral flame is burning smoothly, actuation of the cutting oxygen control will disclose the type of cutting flame created. It may be necessary to readjust the neutral preheating flame while the control lever is depressed, to make sure that it remains neutral while cutting.

(4) The line to be cut should be marked on the metal with a soapstone or chalk. Then place the metal so that this line is beyond the end of the welding bench. If an exceptionally straight cut is desired, clamp a bar of steel across the piece of material to guide the torch.

(5) Hold the torch in the right hand so that there is instant and positive control of the oxygen control lever. The left hand should be used to steady and guide the cutting torch. A fire brick or some other similar object placed on top of the material to be cut will provide a good rest for the left hand and help steady the torch. If the cutting tip wavers from side to side, a wide kerf will be made. This will

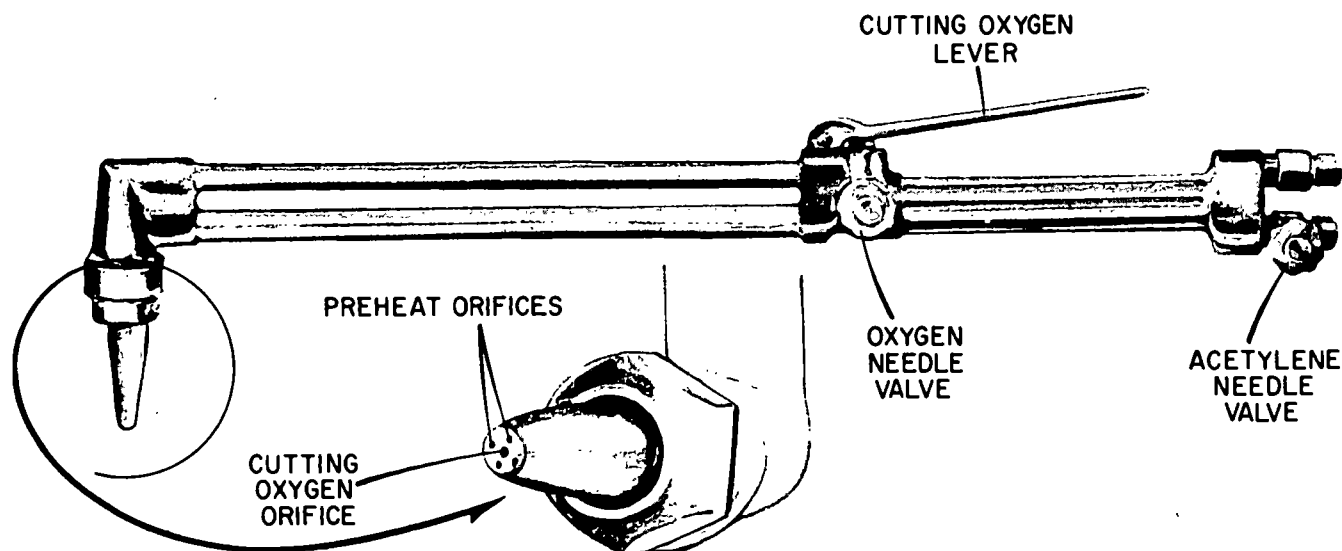


Figure 304. Cutting torch.

result in a wide cut, slower speed, and greater oxygen consumption.

(6) Begin cutting at the edge of the piece (fig. 305). Hold the tip perpendicular to the surface of the metal, keeping the inner cone about 1/16 inch from the line. Hold the flame at this point until a spot in the metal turns bright red, then gradually depress the oxygen control lever. As soon as the cutting starts, there will be a shower of sparks from the lower side of the material and the oxygen control lever should then be fully depressed.

(7) When the cut has been started all the way through the material, move the torch slowly but steadily along the line. The motion of the cutting torch should be just fast enough so that the cut continues to penetrate completely without excessive oxidation or melting.

(8) If the torch is moved too slowly, the heat from the preheating flame will tend to melt the edges of the cut, producing a ragged appearance or, at times, fusing the metal together again. On the other hand, if the torch is moved too rapidly, the cutting jet will fail to go through the material and cutting will be stopped. Should this happen, immediately release the lever, closing the cutting oxygen valve, and reheat at the point where the cutting stopped, until it is a bright red. When the oxygen valve is reopened, the cutting will start again.

(9) When the cut is finished, the cut section may stick to the main piece. This means that some of the slag produced by the cutting action has bridged across the bottom of the two pieces and on cooling has formed a thin crust which holds them together. The crust is quite brittle,

however, and a smart blow from a hammer will break it and separate the pieces.

b. Safety Precautions.

(1) Use no oil, grease, or any other lubricant on welding or cutting apparatus. Never allow oil or grease to come in contact with oxygen under pressure.

(2) Always use the proper tip or nozzle, and operate it at the proper pressure for the particular work involved. This information should be taken from tables supplied with the equipment.

(3) Do not experiment with or change regulators in any way. Always use regulators with the gas for which they were designed.

(4) Do not use matches for lighting torches; a serious hand injury may result. Use friction lighters.

(5) Do not light torches from hot metal, especially in a confined space. An explosive mixture of acetylene and oxygen in a confined space may cause damage or personal injury when ignited. Do not allow such a mixture to accumulate.

(6) Always wear goggles when working with a lighted torch. Use only goggles designed specifically for welding use.

(7) When extinguishing the torch, close the acetylene valve first, then close the oxygen valve.

201. Brazing

Originally, brazing meant joining with brass, or "brassing." As the process was improved and new joining alloys were developed, the term assumed its present meaning—a group of thermal joining processes in which the bonding material is a nonferrous metal or alloy with a melting point

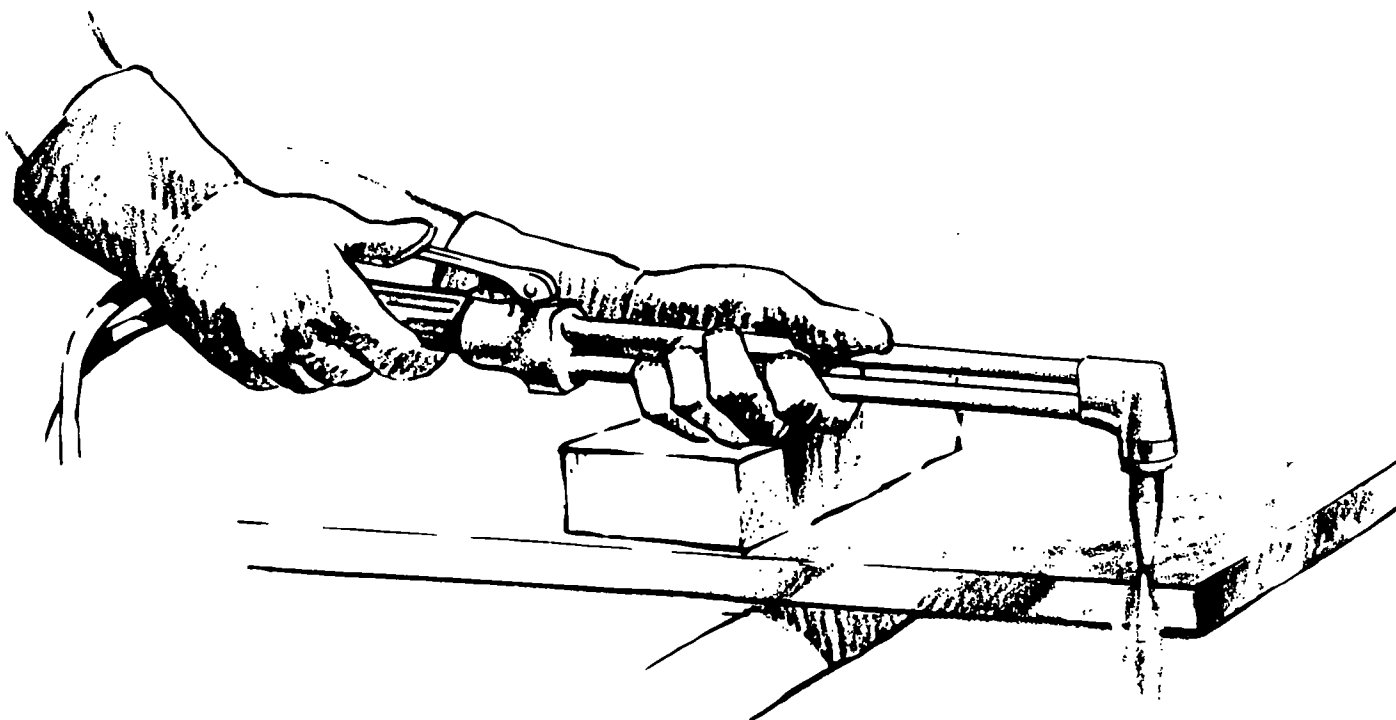


Figure 305. Starting the cut.

higher than 800° F, but less than the metals being joined. Brazing, therefore, includes silver soldering, bronze welding, and hard soldering. Brazing requires less heat than welding, and therefore may be used to join metals that are injured by high heat. The strength of brazed joints is not so great as welded joints, however, and, for this reason, brazing is not used for structural repairs on aircraft. As the definition of brazing implies, the base metal parts are not melted. The brazing metal adheres to the base metal by molecular attraction and intergranular penetration; it does not fuse and amalgamate with them. The usefulness of brazing is easily recognized when the many metals that can be joined by this process are considered. Brazing is applicable to the joining of cast iron, malleable iron, carbon steels, alloy steels, wrought iron, galvanized iron and steel, copper, and brass, bronze, and nickel alloys. It is also used to join dissimilar metals, such as cast iron to steel, or steel to copper. Its principal use is in maintenance, making and repairing tools, jigs, and machinery. In this field it has many applications and attendant advantages. Among these are the relatively low temperatures involved, reduced chance of an excessively annealed area near the brazed joint to stand heavy compression and impact loads.

a. Brazing Technique.

(1) In brazing a joint, first bevel down the edges as in welding steel. Clean the surrounding surfaces of dirt, rust, etc., then select the proper brazing alloy (rod) for the job.

(2) The brazing alloys are graded A, B, C, and D. Grades A and B with melting points of about 1,600° F., are used for strong connections on steel, cast iron, brass, bronze, and general brazing of nickel alloys. Grades C and D are suitable for brazing steel parts that are to be subjected to heat treatment under 1,600°F., after brazing. The melting point of grade C varies from 1,650° to 1,760°F., and that of grade D from 1,725° to 1,825°F.

(3) Because of its higher melting point, grade D brazing alloy is more difficult to apply than grade C, but is preferable with chrome-vanadium and chrome-molybdenum steel. When selecting a brazing alloy, choose one whose melting point is at least 100°F. less than the metal being joined.

(4) A brazing flux is necessary to obtain a good union between the base metal and the filler metal. A good flux for brazing steel is a mixture containing two parts borax and one part boric acid. Use a neutral torch flame and move it with a slight, semicircular motion.

(5) Preheat the base metal slowly with a mild flame; and when it reaches a dull red heat (in the case of steel), heat the rod to a dark or purple color and dip it into the flux. Enough flux adheres to the rod and it is not necessary to spread it over the surface of the metal.

(6) Bring the filler rod near the tip of the torch and let the molten bronze flow over a small area of the seam. The base metal must be at

the flowing temperature of the filler (rod) before it will flow into the joint. The brazing metal melts when applied to the steel and runs into the joint by capillary attraction. Continue adding the rod with a rhythmic dipping action so that the bead will be built to a uniform width and height. Complete the job rapidly and with as few passes of the rod and torch as possible.

(7) The ideal brazing job is completed in one pass. Avoid multiple layers; and if the job requires more than one pass, always remove and replace the spent flux before applying succeeding layers of filler rod.

(8) It is important that the brazing temperature be carefully controlled. If the base metal is heated excessively above the flow temperature of the brazing alloy, the bronze will boil when added and the low melting point alloys of the bronze will burn out, leaving the bronze porous and brittle. On the other hand, if the base metal is not hot enough, the bronze will not flow smoothly, but will form elusive drops which roll off as fast as the bronze is applied. After finishing the job, allow it to cool slowly.

b. Brazing Cast Iron to Steel.

(1) To braze cast iron to steel, flow molten bronze from a filler rod over the hot surface of the metal to be joined to obtain a solid bond between the edges of the seam.

(2) Heat the work to be joined to a temperature slightly above the flow point of the brazing alloy. In the case of steel, this point is determined when the metal reaches a dull red color. Metals which lose their original qualities when melted can thus be joined by brazing without undergoing loss of those qualities.

(3) Brazing is usually the best method of joining unlike metals (copper and steel) or two like pieces of metal such as malleable cast iron which has been heat-treated.

(4) Since the base metal is not melted in brazing, the joining process is greatly simplified. The preheating necessary in fusion welding is largely eliminated.

(5) In deciding whether brazing of a joint is justified, remember that a metal which will be subjected to a sustained high temperature in use should not be brazed.

c. Brazing Brass.

(1) Brazing, rather than welding, is the most effective method of joining brass, because such technique requires a filler rod with a melting point slightly lower than the base metal. Thus melting of the base metal is eliminated.

(2) Brass, in its simplest form, is an alloy

of copper and zinc, although other metallic elements are often added to improve its characteristics.

(3) One of the best of these alloys, consists of 62 percent copper, 0.5 to 1.5 percent tin, 0 to 0.10 percent iron, 0.20 percent lead, and the remainder zinc. Its three advantages are high strength, toughness, and resistance to corrosion. It comes in bar, plate, rod, sheet, and strip form, and in soft, half-hard, and hard condition.

(4) Brass has few uses in aircraft, other than in pipe fittings, and, consequently most of the brazing will be in connection with general repair work on shop equipment, not on aircraft.

(5) The torch flame with brass should have a slight excess of oxygen—one of the very few instances where an oxidizing torch flame is used. Be especially careful in applying heat to brass to avoid burning or oxidizing the zinc content of the brass.

(6) Any good commercial brazing and welding flux will do for this operation, or, in an emergency, borax diluted with boric acid or sodium carbonate may be used. Apply the flux by dipping the hot end of the filler rod in the mixture or by painting the dissolved flux on the rod. Flux protects the hot metal from the air and other gases by forming a film over it, and also cleans the hot brass of oxides formed during the welding process.

(7) The filler rod for brass should have approximately the same composition as the base metal. As pointed out earlier, a rod with a slightly lower melting point than the base metal gives the best results. Use either a grade A or B rod for this job. Two commercial filler rods which are also good are Tobin bronze and manganese bronze rods.

(8) The joints used in brazing brass are the same as those used in welding.

(9) Be sure to clean the surface with a file or abrasive cloth and allow for expansion and contraction. Thick pieces of brass must be beveled by filing or by some other mechanical method. Never bevel brass by melting or cutting since this method destroys the zinc in the brass. To reduce the amount of heat required for the actual brazing and lessen the danger of warping, preheat heavy brass parts.

202. Silver Soldering

a. Silver soldering is one of the several methods of brazing. The principal use of silver solder in aircraft work is the fabrication of high-pressure oxygen lines, and other parts which must withstand vibration and high temperature. Silver solder is used extensively to join copper and

its alloys, nickel, and silver, as well as various combinations of these metals, and thin steel parts (table 53).

b. Silver solder can be obtained in several different grades with silver content ranging from 14.5 to 66 percent, and melting points varying from 1,160° to 1,430°F. The standard forms of silver solder are strips and wires, but it is also made in rod form.

c. If the job to be performed is one in which the solder may be placed in the joint before ap-

plying heat, use the strip form. For joints requiring the solder to be applied after heating, use the wire form.

d. It is necessary to use flux in all silver soldering operations because of the necessity for having the base metal chemically clean without the slightest film of oxide to prevent the silver solder from coming into intimate contact with the base metal.

e. A paste flux is used generally in most silver soldering. If a prepared flux is not available, a

Table 53. Silver Solders

Class	Silver ¹ (percent)	Copper ¹ (percent)	Zinc ¹ (percent)	Other ¹ (percent)	Melting point (°F.)	Flow point (°F.)	Uses
0	20	45	35	--	1,430	1,500	Ordinary brazing purposes where higher physical properties are required than provided by brazing alloys and where service or appearance does not require a high silver content.
1	45	30	25	---	1,250	1,370	Intended for the general range of silver soldering.
2	65	20	15	---	1,280	1,325	High silver content used where high strength, resistance to corrosion, and good appearance is required.
3	15	80	--	² 5	1,200	1,300	Intended for brazing copper and copper base alloys. Do not use for ferrous alloys.
4	50	15	16	³ 19	1,160	1,175	General purpose intended for brass, copper, ferrous metals and particularly nickel-copper alloys and alloy steels.
5	50	15	15	³ 17	1,195	1,270	Same as class 4, but where design requires addition of a fillet or where close tolerance cannot be maintained and filling is necessary.
				43			Also for hard materials such as cemented carbides for tools.
6	50	15	25	³ 10	1,166	1,190	Same as class 4.
6A	49-51	17-19	20-24	⁵ 9-11	1,160	1,185	Same as class 4.

¹Approximate percent.

²Phosphorus.

³Cadmium.

⁴Nickel.

⁵Cadmium.

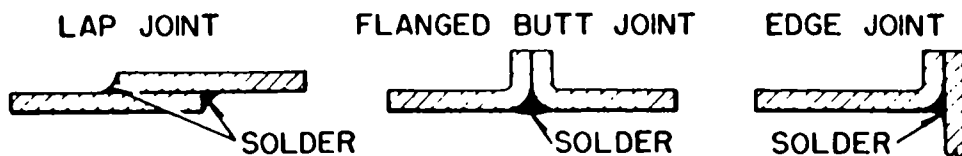


Figure 306. Recommended joints for silver soldering.

mixture of 12 parts of borax and 1 part boric acid is satisfactory for high-melting-point silver solder. Prepared flux begins to melt at 800°F., 1,600°F. It melts at a slightly lower temperature than the solder.

f. The joint must be physically clean, which means free of all dirt, grease, oil and paint, and also chemically clean—minus all traces of oxide film. After removing the dirt, grease, and paint, remove any oxide which may be present by filing the piece until bright metal may be seen. During the soldering operation, the flux continues the process of keeping oxide away from the metal.

g. Joints to be silver soldered must have smooth edges and must fit tightly together. Only a film of silver solder is usually needed for a sound joint. Strength is not added to the joint and expensive solder is wasted if it is used as filler metal.

h. In figure 306 are presented three recommended types of joints for silver soldering. Flanged, lap, and edge joints, in which the metal may be formed to furnish a seam wider than the base metal thickness, furnish the type of joint which will bear up under all kinds of loads. If a lap joint is used, figure the amount of lap according to the strength needed in the joint. Here is a handy rule of thumb: For strength equal to that of the base metal in the heated zone, the amount of lap should be four to six times the metal thickness for sheet metal and small diameter tubing.

i. The oxyacetylene flame for silver soldering should be neutral, but may have a slight excess of acetylene. It must be soft, not harsh. During both preheating and application of the solder, hold the tip of the inner cone of the flame about one-half inch from the work. Keep the flame moving so that the metal will not be overheated.

j. If the piece is large, preheat a considerable area around the joint before applying the solder, especially if the base metal conducts heat rapidly. When soldering two pieces which have different thicknesses or which conduct heat with unequal speed, gage the preheating so that both parts reach the soldering temperature at the same time.

k. When both parts of the base metal are at the right temperature (indicated by the flow of flux), begin applying solder to the surface of

the under or inner part at the edge of the seam. It is necessary to simultaneously direct the flame over the seam and keep moving it so that the base metal remains at an even temperature.

203. Soft Soldering

Soft soldering is used chiefly for copper, brass, and coated iron in combination with mechanical seams—that is, seams that are riveted, bolted, or folded. It is also used where a leakproof joint is desired, and sometimes for fitting joints to promote rigidity and prevent corrosion. Soft soldering is generally performed only in very minor repair jobs. This process is also used to seal electrical connections. It forms a strong union with low electrical resistance. Soft solder yields gradually under a steadily applied load and should not be used unless the loads transmitted are very low. It should never be used as the sole means of attachment of two structural members.

a. Soldering Copper.

(1) A soldering copper (called a soldering iron if it is electrically heated) is the tool used in soldering. Its purpose is to act as a source of heat for the soldering operation. The bit or working face, is made from copper, since this metal will readily take on heat and transmit it to the work.

(2) The bit should be relatively blunt. If it is too thin and pointed, it will cool too rapidly. Figure 307 shows a correctly shaped bit.

(3) Soldering coppers may be heated by blow-torch or a gas flame. Electric soldering irons have an internal heating element and are especially useful where a constant heat is required, as in soldering electrical connections.

b. Tinning the Copper.

(1) To tin the copper, first heat it to a bright red, then clean the point by filing until it

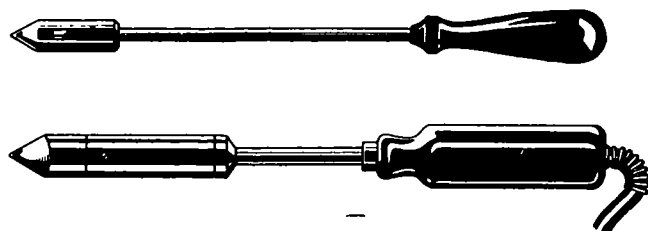


Figure 307. Soldering copper and soldering iron.

is smooth and bright. No dirt or pits should remain on its surface. After the copper has been mechanically cleaned, it should be reheated sufficiently to melt solder, and chemically cleaned by rubbing it lightly on a block of sal ammoniac. (If sal ammoniac is not available, powdered resin may be used.) Then apply solder to the point and wipe with a clean, dry or damp cloth.

Note. When heating the soldering copper, the heating flame should not be directed on the point as it will form an oxide and prevent good tinning.

(2) The last two operations may be combined by melting a few drops of solder on a block of sal ammoniac (cleaning compound) and then rubbing the soldering copper over the block until the tip is well coated with solder. A properly tinned copper has a thin unbroken film of solder over the entire surface of its point.

(3) If the point of the copper needs reshaping, it should be done by forging. In performing this step, remove all of the oxides and reheat the copper to a bright red. Using a heavy hammer, forge the point to the desired shape on an anvil, then tin in the usual manner.

(4) When using the copper, occasionally dip the point in a solution of one part of sal ammoniac to 30 parts of water. (Keep this solution in an earthenware jar.) If sal ammoniac is not available, powdered resin will serve to tin the point.

(5) The fluxes ordinarily used for soft soldering are solutions or pastes containing zinc chloride. The liquid or paste medium holding the flux material is evaporated by the heat of the soldering operation, leaving a layer of flux on the work. At the soldering temperature, the flux is melted and practically decomposed with the liberation of hydrochloric acid. This acid then dissolves the oxides from the solder and the work. The melted flux also forms a protective film on the work preventing further oxidation. Zinc chloride flux is used on iron, copper, brass, and galvanized iron. Muriatic acid is often used in its raw state as a flux for soldering galvanized iron and zinc.

(6) Because zinc chloride fluxes have a corrosive action, it is necessary to employ a non-corrosive flux for work on electrical connections or other places where all traces of flux cannot be removed. Resin, either in powder or paste form, is the most commonly used flux of this type.

(7) Use a noncorrosive commercial flux or a resin flux for electrical connections or where it is impossible to remove all traces of flux from the work. Zinc chloride and other corrosive fluxes must be washed from the work to prevent corrosion.

c. Types of Soft Solder.

(1) Soft solders are chiefly alloys of tin

and lead. The percentages of tin and lead vary considerably in various solders, with a corresponding change in their melting points, ranging from 293° to 592°F. "Half-and-half" (50-50) solder is a general purpose solder and is most frequently used. It contains equal proportions of tin and lead and melts at approximately 360°F.

(2) Soft solders are usually supplied in bar or wire form, although they can also be obtained in granulated form for jobs requiring large quantities of solder. Some wire-shaped solders have a core of flux. The most popular solder of this type has a core of resin and is used chiefly on electrical connections.

(3) The film of solder between the surfaces of a joint must be kept thin to make the strongest joint.

d. Soldering Technique.

(1) The application of the melted solder requires somewhat more care than is apparent. The parts should be locked together or held mechanically or manually while tacking, as shown in figure 308. To tack the seam, touch the hot copper to a bar of solder, then use the drops of solder adhering to the copper to tack the seam at a number of points.

(2) Hold a hot, well-tinned soldering copper so that its point lies flat on the metal at the seam, while the back of the copper extends over the seam proper at a 45-degree angle, and touch a bar of solder to the point. As the solder melts, draw the copper slowly along the seam as in figure 309. Add as much solder as necessary without raising the soldering copper from the job. The melted solder should run between the surfaces of the two sheets and cover the full width of the seam. Work along the seam only as fast as the solder will flow into the joint. When the copper cools, reheat it or take another hot copper. Resume your work by remelting the solder



Figure 308. Holding the parts together.



Figure 309. Soldering a seam.

where the operation stopped, and go on from there.

(3) In another type of soldering known as sweating, both surfaces of the pieces to be joined are tinned, then held together and heated with a soldering copper or blowtorch until the solder melts and begins to run out. Remove the copper or torch and keep the parts in close contact by pressure until the solder cools and sets.

e. Post-Soldering Treatment.

(1) Whether doing hard soldering or soft soldering, the joint must be cleaned when finished. This means the removal of all flux that might cause corrosion or prevent paint from adhering. In some cases, the joint is immersed in a "bright dip" to restore the color.

(2) If the base metal is nonferrous—that is, not made from iron ore—a good solution for removing flux consists of 1 fluid ounce sulfuric acid, 1.5 ounce sodium bichromate, and 1 gallon of water.

(3) Boil ferrous metals in a 10 to 15 percent solution of caustic soda for 30 minutes to eliminate the flux. In either case, rinse the metal thoroughly in clean water after treating it.

(4) The job may require that metal which has been discolored by heat, in the soldering process, be restored to its original color. The color of copper and brass particularly seems sensitive to heat. The remedy is a "bright dip" consisting of 68 fluid ounces sulfuric acid, 20 fluid ounces nitric acid, 0.12 fluid ounce of hydrochloric acid, and 40 fluid ounces of water. Following this bath, rinse the metal thoroughly in clean, running water.

(5) Scale which is caused by the heating of steel parts may be removed by a light sand blast.

204. Safety Precautions

Gas welding, brazing, and soldering operations can be very dangerous. Strict adherence to all applicable safety precautions must be observed when performing these operations. Some of the common hazards encountered and the precautions to be followed when operating welding equipment and/or supervising a welding shop are as follows:

a. Use only approved apparatus, such as torches, regulators, hose, valves, and accessories that have been examined, tested, and found to be safeguarded in accordance with accepted standards.

b. Only qualified operators are allowed to perform welding, brazing, and soldering operations.

Note. This does not preclude on-the-job training of non-qualified personnel if supervised by a qualified operator.

c. While the equipment is in use, it must be frequently inspected for evidence of leaks in the hose, couplings, valve stems, or other points of the system. Otherwise, an explosive mixture of gas and air may accumulate with serious results.

d. Positive ventilation of the welding shop/area must be provided and maintained during all welding, cutting, or heating operations to prevent suffocation, fire, and explosion due to gas leaks; heat prostration, and/or illnesses such as metal fume fever or metal poisoning caused by breathing toxic vapors which may be formed under certain conditions.

e. If all fire hazards cannot be removed from the area of welding operations, fire guard must be properly instructed and posted in the vicinity.

f. Suitable fire-extinguishing equipment of approved types must be maintained near all welding and/or cutting operations.

g. Protective clothing must be provided and worn at all times when welding and/or cutting operations are being performed.

h. Not only welding and cutting operators, but also other personnel such as helpers, inspectors, etc., who remain in the vicinity, must use suitable helmets, hand-held shields, or goggles during all welding/cutting operations, in order to protect their eyes from stray flashes, reflected glare, and flying particles.

i. After welding/cutting operations are completed, the operation should mark the hot metal or provide some other means of warning other workers who may inadvertently come in contact with the hot metal.

Section II. ELECTRIC ARC WELDING

205. General

During World War II, it was necessary to build aircraft, ships, tanks, and various other implements of war in the least time possible. A great deal of credit for the rapid production of these items during the all-out of war effort is credited to the use of arc welding. Prior to this time, progress in the field of arc welding was comparatively slow. It took time for industry to recognize its many advantages, and the supply of equipment and experienced operators was limited. Since World War II, many new developments have been made in arc welding equipment; and now arc welding is one of the most important metal-joining processes used in aircraft construction. Arc welding offers such advantages as less warping and buckling; less effect on the temper of the metal because of faster welding and more concentrated heat; ability to produce strong, sound, and ductile welds; suitability for practically all types of aircraft metals; and production of satisfactory welds in heavy structural members, as well as light surface skins.

206. Theory of Arc Welding

a. Electric arc welding is a fusion process based on the principle of generating heat with an electric arc jumping an airgap to complete an electrical circuit. This process develops considerably more heat than an oxyacetylene flame. In some applications it reaches a temperature of approximately 10,000°F.

b. The welding circuit consists of a welding machine, two leads, an electrode holder, an electrode, and the work to be welded. The electrode, which is held on the electrode holder, is connected to one lead, and the work to be welded is connected to the other lead. When the electrode is touched to the metal to be welded, the electrical circuit is completed and the current flows. When the electrode is withdrawn from the metal, an airgap is formed between the metal and the electrode. If this gap is of the proper length, the electric current will bridge this gap to form a sustained electric spark, called the electric arc.

c. The instant the arc is formed, the temperature of the work at the point of welding and the welding electrode increases to approximately 6,500°F. This tremendous heat is concentrated at the point of welding and in the end of the electrode, and simultaneously melts the end of the electrode and a small part of the work to form a small pool of molten metal commonly called the crater.

d. Under the intense heat developed by the arc, a small part of the work to be welded is

brought to the welding point almost instantaneously, and tiny particles of molten metal are formed at the end of the electrode. These tiny particles, or globules, are then forced across the arc and deposited in the molten crater in the work. Because of this fact, it is possible to make overhead welds.

207. Arc Welding Equipment

a. Welding Machines.

(1) The function of the welding machine is to supply and control the current for arc welding. The means of supplying current of the appropriate voltage is provided by a motor generator or a transformer. Controlling and adjusting the arc length (necessary for the work to be accomplished) is provided by switches and selectors on the welding machine. Provisions for attaching two cables are provided on the welding machine. The ground cable is attached to the ground cable connector on the machine, and the other end is attached to a ground plate or clamp which is attached to the work.

(2) The welding cable is attached to the welding cable connector on the machine, and the other end is attached to the electrode holder. Figure 310 shows a typical arc welding circuit.

(3) Arc welding machines are classed as either direct-current (d-c) type welding machines or alternating-current (a-c) type welding machines. Each type has its advantages and disadvantages peculiar to the type of current produced. Advantages such as initial cost, portability, and operating expenses are claimed for each class of welding machines. However, from a welder's standpoint, dc equipment offers fine current adjustments and choice of polarity. An ac welder eliminates practically all arc blow (which is troublesome to welders using dc equipment) especially when making heavy fillet or deep groove welds.

(4) Electric arc welding machines are manufactured in sizes ranging from 100 to 600 amperes for manual welding. Machine sizes are based

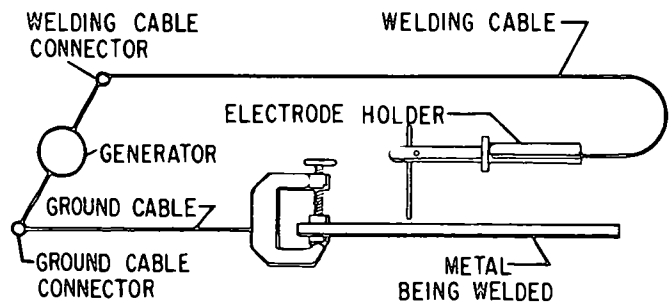


Figure 310. Arc welding circuit.

on their amperage output. For example, a 100-ampere machine will deliver 100 or more amperes (the output is rated conservatively by most manufacturers). Naturally, the range in sizes of arc welding machines is governed by the class and range of work for which is to be used.

(5) The 200-ampere machine is the machine which most economically satisfies the needs of aircraft welding. A machine of this size will rapidly weld the light metals used in aircraft and can also be used for most of the maintenance in the shop. Each type welding machine is discussed separately in the following paragraphs.

b. Direct Current (DC) Welder.

(1) A direct-current welder consists of a direct-current generator driven by a suitable type of motive power. The voltage of such a generator will usually range from 15 to 45 volts across the arc, although any setting is subjected to constant variation due to arc conditions.

(2) A fairly wide range of current output is necessary to accommodate the various kinds of work. The range of current will also vary, depending upon the type unit and work for which it was designed.

(3) In direct-current welders, the generator is of a variable voltage type and so arranged that the voltage automatically adjusts itself to the demands of the arc. However, the open circuit voltage is manually set to the correct range by means of a rheostat mounted on the control panel. Amperage of the welding current is manually adjustable, and is usually set to the proper range by means of a reactance arrangement, or selector switch which taps into the field coils of the generator at different points to increase or decrease its strength. When both voltage and amperage are adjustable by means of individual controls, the machine is referred to as a dual-control type. The dual-control machine is the most popular in use today. Figure 311 shows a dual-control direct-current welding machine.

(4) Another system employed to a limited extent makes use of adjustable generator brushes for the control of the current. Machines of this type are provided with one control which proportionately varies both amperage and voltage by the movement of the brush assembly.

(5) When a power supply is available, welding generators are driven by means of an electric motor. The armatures of both generator and motor are usually on a single common shaft. However, some of the older machines are arranged whereby the motor drives the generator through a flexible coupling.

(6) In many instances, arc welding must be performed in places where a power supply is not available. Portable gasoline-engine-driven

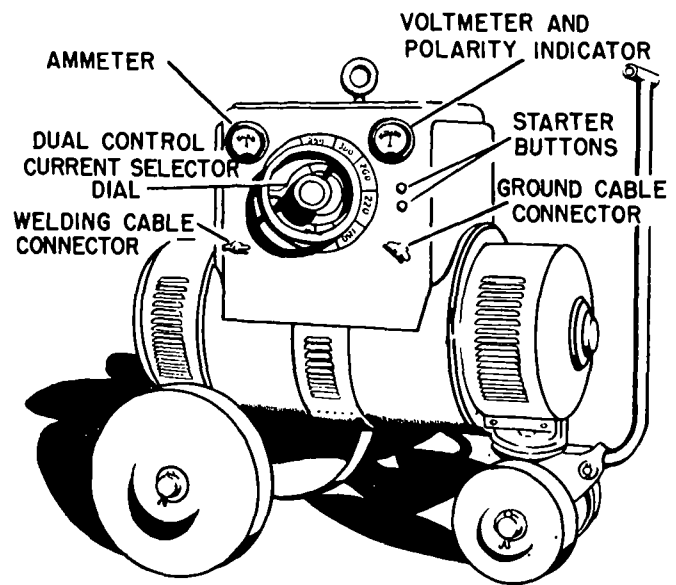


Figure 311. Dual-control direct-current welding machine.

generators are particularly adaptable in such cases, as they are available in compact units easily transported from place to place. The engine used for this purpose must be fitted with a suitable governor to compensate for the varying loads imposed by the welder.

c. Alternating-Current (AC) Welders.

(1) The alternating-current welder shown in figure 312 derives its welding current from a core transformer. The primary coil is connected directly to the power line, and the secondary coil supplies the welding current. Current control, which varies in different models, is accomplished by either a bridge reactor, movable coil, movable core, or by tapping the secondary coil. All means of current control, except the tapped secondary coil method, offer continuous control.

(2) The ac welder has rapidly gained in popularity because of advances in machine design and the development of heavy-coated electrodes especially designed for alternating current welding.

d. Rectified (DC) Welders.

(1) This type welder is being used extensively for arc welding in the Navy and is one of the most recent developments in the field of arc welding. The dc rectifier type arc welder combines the advantages of both dc and ac welding without their inherent disadvantages.

(2) The dc rectifier arc welding machine combines a three-phase transformer, a three-phase adjustable reactor, and a three-phase, full wave, high voltage plate type rectifier.

(3) The efficiency of the dc rectifier arc welder is rated at 66 percent as compared to 54 percent for motor generator welders. In addition to offering economy, it also affords desirable

welding characteristics such as extremely rapid responses to changes in current and voltage conditions. The most outstanding advantages for the machine, however, are claimed on its operation where welding is done at low current densities.

e. Maintenance of Welders.

(1) Proper maintenance of arc welding machines is very important. Because of the dust and grit present in all welding shops, it is necessary to periodically check and clean the machine in order to keep it in the proper working order. The following cleaning instructions apply to most arc welding machines.

Note. Prior to attempting any maintenance inside the machine, make sure that the power source is disconnected to avoid any possibility of fatal shock.

(2) Forced draft is used to cool most welding machines; and because of this fact, particles of dirt are carried throughout the unit. Under average conditions, the machine should be cleaned with dry, compressed air at least once each month. This may readily be done by removing the dust covers and shields. Should the machine appear greasy at the time of cleaning, it should be dismantled and thoroughly washed with dry cleaning PD-680 solvent. During the regular monthly cleaning, an inspection should be made of the condition of the switch points, brushes, commutator, and bearings.

Note. All maintenance performed on the welding machine should be done in accordance with the maintenance instruction manual for the machine concerned.

(3) The machine should be given a thorough greasing at 4- to 6-month intervals. This may follow the cleaning operation and should include all bearings in the unit. Too much grease may be as harmful as not enough, as a surplus may be thrown upon the commutator. Grease on

the commutator may result in serious damage or a fire hazard.

(4) To properly grease a bearing of the type used in welding machines, the plug should be removed on the lower side of the bearing boss and the machine started. Grease may then be injected into the fitting until it begins to emerge from the plug hole. Allow the machine to run for several minutes to force out any pressure on the grease, then replace the plug. Only an approved grease should be used.

(5) The brushes and commutators of both the motor and generator are subject to considerable wear. Brushes worn so that spring tension is appreciably reduced must be replaced to maintain proper efficiency of the machine. Although new brushes are formed to fit the commutator, they must often be sanded to give proper amount of contact. This is done by wrapping a strip of No. 00 sandpaper around the armature and turning it by hand until the brushes have been worked down to a perfect fit. Never use emery cloth.

(6) Brush springs weakened from overheating should also be replaced to insure positive brush contact.

(7) Each time brushes are replaced, the commutator should be checked for cleanliness and wear. If a deposit of graphite from the brushes is found, it may be removed by holding a piece of No. 00 sandpaper against the commutator while the armature is in motion. Ridges or pockets on the surface of the commutator will require the removal of the armature so that it may be "trued up" on a lathe. Only a light cut should be taken, and the mica separators between the bars of the commutators must be undercut from one sixty-fourth to one thirty-second inch after the truing operation. Although a special cutter should be used for this purpose, a hacksaw blade ground to the proper thickness will serve in an emergency.

(8) All electrical switch contacts should be sanded clean if pitted. Parts that have been badly burned should be replaced. At least once each year, the windings of the generator and motor should be inspected and, if found dry or cracked, coated with insulating varnishes or resins carried in stock for this purpose.

f. Welding Cable.

(1) The welding current is conducted from the generator to the work by multistrand, well-insulated copper cables, two of which are required to complete the circuit between the welding machine and the work. One cable, extra-flexible, is used between the welding machine and the electrode holder. The other cable is the ground and is connected between the work and

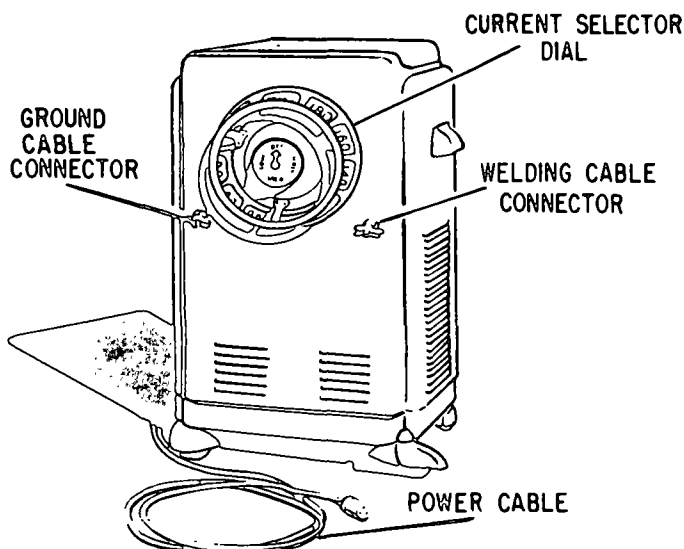


Figure 312. Alternating-current welding machine.

the machine. It need not be as flexible as the electrode holder cable, although similar types of cable are sometimes used for both.

(2) Flexible cable is designed especially for welding. It derives its flexibility from its construction, since it is made of thousands of very fine wires enclosed in a durable paper wrapping which allows the conductor to slip readily within its rubber insulation when the cable is bent. The rubber also contributes to its flexibility. The ability of the cables to withstand wear and abrasion is provided by a tough, braided cotton reinforcing and by the composition and curing of the waterproof rubber covering, which also provides a smooth finish.

(3) The size of the cable is determined by the size of the welding machine and the distance of the work from the machine. As these factors increase, the size of the welding cables must also increase. When the cable is too small in relation to the amperage used, it will become overheated. A cable which is too small will not carry sufficient current to the arc without overheating, but the larger the cable the more difficult it is to handle.

(4) Selection of the size of the cable has a definite and important bearing on welding efficiency. Table 54 offers a guide for selection of the correct cable to use on various machines.

(5) It is further recommended that the longest length of 4/0 cable for a 400-ampere welder should not be greater than 150 feet, and for a 600-ampere welder not more than 100 feet. For greater distances, the cable sizes should naturally be increased despite the fact that cables of such length and size are difficult to handle. Rather than increase the size of the welding cable, move the machine closer to the work.

g. Electrode Holders.

(1) An electrode holder is essentially a clamping device for holding the electrode. It is provided with a hollow, insulated handle through which the welding cable is passed to connect with the electrode clamping device.

(2) The advantage of an insulated electrode holder lies in the fact that it may be touched to any part of the work without danger of short circuiting. The clamping device is made of an alloy which is a good conductor of electricity and durable under high temperature and constant use. The clamp is designed to hold the electrode securely in any position and to permit quick and easy change of electrodes. An electrode holder should be light in weight to permit ease of handling yet sturdy enough to withstand rough usage. Typical electrode holders are shown in figure 313.

(3) Electrode holders are made in a variety of sizes, and each manufacturer has his own system of designation. However, any catalog description of an electrode holder gives the maximum amperage and range of electrodes by diameters which the holder will accommodate. The size used is dependent upon the amperage rating of the welding machine; that is, a larger holder must be used with a 300-ampere welder than with a 100-ampere machine. If the electrode holder is smaller than the type which should be used for a particular machine, the holder will overheat.

Caution: The fully insulated type electrode holder should always be used with ac welding machines since this type holder gives the operator better protection from shock. These holders should be examined to see that there are no exposed screwheads or rivets which might come in contact with the operator and cause a serious shock.

h. Grounding.

(1) In many cases where trouble has occurred on a welding job, it has been traced to a poor ground connection. Like any other electrical circuit, it takes only one poor connection to destroy the efficiency of the welding circuit.

(2) There are three common methods used to attach the ground cable to the work—bolting, clamping and tack welding. The bolting method of grounding is generally used when all welding is done on a bench or any permanent fixture with the lug on the end of the ground cable being bolted to the bench. The clamping method of grounding employs a C clamp or a clamp of special design permanently attached to the ground cable which is attached to the welding table or bench. The tack welded method of grounding employs a ground plate which is bolted to the ground cable and tack welded to the work or bench. This method makes a very good ground; however, in some cases its use is not desirable.

(3) In addition to the grounding of the work or welding bench, a ground should be provided on the welding machine for grounding the welding machine frame and inclosure preferably located near the power supply connection point. A power supply ground serves to reduce or eliminate shocks from stray currents as well as protect against imposing full supply voltage on the output terminals in the event of a breakdown of the insulation.

i. Protective Equipment.

(1) Exposure of the eyes to the infrared and ultraviolet rays accompanying electric arcs often results in eye-burn or "sand in the eyes," as it is commonly called by arc welders, and

Table 54. Recommended Cable Sizes

Machine capacity in amperes	Cable lengths		
	Up to 50 feet (Size No.)	50 to 100 feet (Size No.)	100 to 250 feet (Size No.)
Up to 150	2	2	2
200	2	1	2/0
300	0	2/0	4/0
400	2/0	3/0	4/0
600	2/0	4/0	4/0

may cause extreme pain for 24 to 48 hours. In addition to affecting the eyes, exposure to the arc will produce severe sunburn to portions of exposed skin.

(2) To protect the eyes and face, a head shield must be worn. These shields are constructed of pressed fiber and are solid black in color to reduce reflection. They are light in weight and designed to insure comfort to the welder.

(3) Protective shields are provided with a glass window whose standard size is 2 x 4 1/8 inches. The composition of the glass lens is such that it absorbs the infrared and ultraviolet rays and most of the visible rays from the arc. Table 55 lists the recommended welding glass numbers for various welding applications.

(4) The welding lens is protected from metal splatter and breakage by a plain or a chemically treated, clean, nonsplatter glass covering the exposed side of the lens. Green-tinted flash goggles should be worn by the welder to protect his eyes from the flashes of other welders when he removes the shield for purposes such as inspecting his weld. They also protect his eyes when he is grinding, chipping, or cleaning slag. Flash goggles should be worn by all persons

working in the vicinity of arc welding operations.

(5) During any arc welding operation, a continuous shower of sparks and hot molten metal are thrown off by the arc. These may cause burns if permitted to contact the skin; therefore, protective clothing must be worn to shield the welder from the spray sunburn effects of the arc. Leather gloves, preferably of the gauntlet type, protective sleeves of leather, and leather aprons should also be worn at all times. Leather jackets provide excellent protection when welding in the vertical or overhead position. There are many other types of protective clothing, usually made of leather, such as trousers and leggings. Naturally, the type and amount of protective clothing you need will depend upon the position and size of the welding job.

(6) In addition to wearing protective clothing, the welder should keep the collar button on his shirt fastened, and wear ankle-high shoes in preference to oxfords. It is also important that trousers without cuffs be worn and that the legs of the trousers be held down over the shoe tops. Bicycle clips are excellent for this purpose. The welder can protect the top of his head with a brimless white hat. Woolen clothing, which offers more protection than cotton, should be worn, if possible.

(7) When welding indoors, provisions should be made to remove smoke and fumes by mechanical means. When possible, all inside welding should be done in a special room or booth equipped with a suitable hood, ducts, and fan for exhausting the smoke and fumes and replacing with fresh air. If welding has to be performed in areas other than those mentioned above, as much ventilation as possible should be provided.

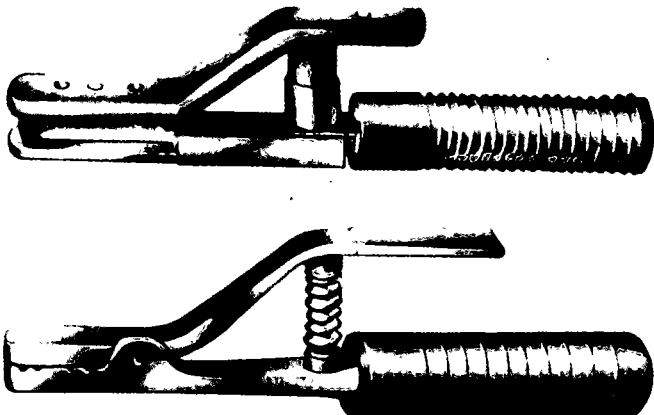


Figure 313. Electrode holders.

208. Types of Electric Arc Welding

The most common types of electric arc welding

are the carbon arc, metallic arc, and inert-gas shielded arc processes. Carbon arc and metallic arc are discussed in this chapter. Inert-gas-shielded arc is discussed in this section.

a. Carbon Arc Welding.

(1) Carbon arc welding is a process of joining two metals together by heating with an electric arc between a carbon electrode and the work and no shielding is used. Pressure may or may not be used, and filler metal may or may not be used. Heat is produced by maintaining an electric arc between the carbon electrode and the work to be welded. Figure 314 illustrates a carbon arc using a carbon electrode.

Table 55. Recommended Welding Glass Numbers

Welding glass number	Arc welding application (amperes)	Electrode diameter (inches)	Ultraviolet (percent transmission)	Infrared (percent transmission)
6	To 30	1/16	0.2	1.5
6	To 75	1/16, 3/32	.1	1.0
10	75 to 200	1/16, 3/32, 1/8, 5/32	.1	.6
12	200 to 400	3/16, 7/32, 1/4	.05	.5
14	Over 400	5/16, 3/8	.05	.3

(2) The carbon electrode serves only as a terminal to create the arc which melts the metal to be welded and does not supply the filler metal. When filler metal is required, it is added separately in the form of a metallic rod in a manner similar to that employed in oxyacetylene welding.

(3) The electrodes may be made of carbon or graphite. The electrodes for manual welding are available in diameters of 5/32 to 1 inch and in 12-inch lengths. For machine welding, the electrodes are available in sizes to meet job requirements.

(4) The carbon arc welding process is similar to oxyacetylene welding in that it is a puddling process; however, the more intense heat of the carbon arc makes it necessary to manipulate or move the arc much more rapidly. Some of the advantages of carbon arc welding are as follows: It may be used where no filler metal is required as in flange butt welding; it may be used for preheating; it may be used to a limited extent for cutting; and it is useful in foundry work.

(5) A distinct disadvantage of carbon arc welding is that it is a puddling process, which makes it unsuitable for vertical and overhead welding. Although the carbon arc welding process

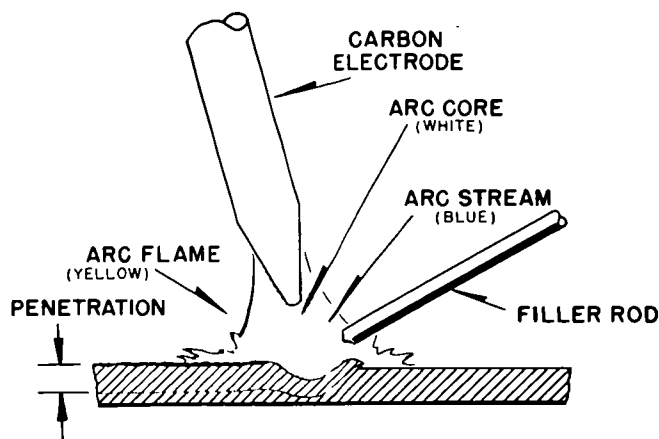


Figure 314. Carbon arc.

ess has advantages in certain applications, it is not as adaptable as the metallic arc process and has been replaced in most hand welding applications by the metallic arc process.

(6) However, the carbon arc welding process is still employed in steel foundries to correct defects in steel castings and for burning out sand spots in castings. It is also employed in some automatic machine welding applications and for limited cutting operations.

b. Metallic Arc Welding.

(1) The metallic arc welding process is a nonpressure fusion welding process which develops welding heat through an arc produced between a metal electrode and the work to be welded. Under the intense heat developed by the arc, a small part of the base metal or work to be welded is brought to the melting point instantaneously. At the same time, the end of the metal electrode is also melted, and tiny globules or drops of molten metal pass through the arc to the base metal. The force of the arc carries the molten metal globules directly into the puddle formed on the base metal, and thus filler metal is added to the part being welded.

(2) By moving the metal electrode along the joint and down to the work, a controlled amount of filler metal can be deposited on the base metal to form a weld bead.

209. Current and Polarity

To understand the meaning of polarity, its relationship to the arc welder, and its use, it is first necessary to become familiar with the basic principles of an electric current. A brief discussion of current and polarity is presented in the following paragraphs.

Electric current is divided into two classifications—direct current (dc), which is electricity flowing in one direction only, and alternating

current (ac), or current flowing alternately in opposite directions. In the latter, the direction of flow is continually reversing itself. Electric current consists of a movement of electrons through an electrical circuit, the movement being from the negative terminal of the battery or generator through the electrical circuit to the positive terminal or pole of the source of electromotive force. In a direct-current circuit, the polarity always remains the same, and the current always flows through the circuit in the same direction; however, in an alternating-current circuit, the current continually reverses direction in keeping with the changes in polarity at the terminals of the ac generator. The polarity of the voltage drop across any electrical circuit, whether it be an arc, a single resistor, or an entire circuit, is determined by the direction of electron flow (current). The sum of all the voltage drops around the circuit equals the potential developed at the terminals of the generator.

a. Alternating Current. As previously mentioned, alternating current is current flowing alternately in opposite directions—the direction of flow is continually reversing itself. There are several advantages in using an ac welding machine instead of a dc machine. The advantages and disadvantages of the ac welding equipment are discussed in the following paragraphs.

(1) *Advantages.* One fundamental advantage of ac welding is that it greatly reduces arc blow (distortion of the arc stream from the intended path). Another is the initial cost, which is generally cheaper for the ac machine, and it is usually less expensive to maintain and operate. In small shops, where the only available power source is a single phase, the ac welder is readily adaptable to a single or multi-phase power outlet of 110, 220, or 440 volts. The ac welding transformers are quiet in operation and are highly recommended for welding in restricted places.

(2) *Disadvantages.* The power available to small shops is often subject to “line surges” to which the transformer welder is extremely sensitive. Alternating-current welding is still handicapped by the fact that suitable electrodes have not been developed for generally satisfactory welding of copper, bronze, aluminum, and other nonferrous metals, as well as for certain hard-surfacing operations. The carbon arc cannot be used satisfactorily because it calls for straight polarity. Alternating current is constantly changing from straight to reverse polarity 50 percent of the time, giving no choice of polarity. Welding with ac requires that additional safety precautions be observed during welding operations. Op-

erators are more subject to shock and burns than from dc equipment.

b. Direct Current. Direct current, as previously mentioned, is electricity flowing in one direction only. The dc welding machine has several advantages over the ac welding machine. The advantages and disadvantages of the dc welding equipment are discussed in the following paragraphs.

(1) *Advantages.* Direct current can be used for welding ferrous and nonferrous metals alike. It can be used where a much greater voltage drop on the electrode or on the plate is essential for satisfactory operation. In the case of many alloys, it is necessary to have a widely different voltage drop on one side of the arc than on the other. Either reverse or straight polarity may be applied to the welding job at hand, depending on the desired characteristics or nature of the weld. The positive side of the arc releases 65 to 75 percent of the heat when using the bare electrode.

(2) *Disadvantages.* The welding operator must be continually on the lookout for arc blow, which is recognized by the persistency of the arc to flare wildly and tend to wander from the path along which the operator is attempting to conduct it. The initial cost of dc welding equipment is more than the ac equipment and is also more costly to maintain and operate. The dc welding machines also require additional power requirements over those required for ac equipment.

c. Welding Current and Voltage. The speed at which a welder travels and the quality of the weld will depend largely on the arc force, which is controlled by the amount of current and voltage being used. The limiting speed is usually the highest speed at which the surface appearance remains satisfactory. An increase in current increases the arc force and penetration. To use higher currents, larger size electrodes may be needed. In general, the first indication of excess current will be poor surface appearance of the weld. As previously mentioned, arc force is controlled by regulating the proper amount of current and voltage, making it necessary for the welding operator to understand their function.

(1) *Voltage.* Voltage across the arc while welding is determined by arc conditions—including length, temperature, and gaseous content, with length of arc the predominant factor. Generally speaking, as long as the current remains constant, arc voltage increases as the arc is lengthened and decreases as the arc is shortened. Experience has shown that the arc is more sta-

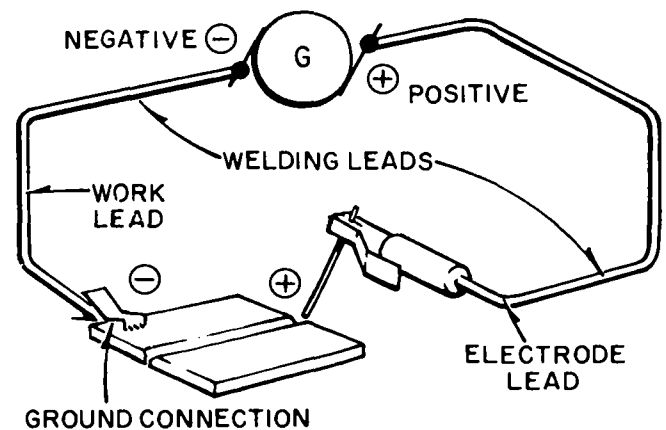
ble and easier to maintain without interruptions caused by air currents, magnetic conditions, etc., if the open circuit voltage is at least twice the actual arc voltage. Therefore, for practical purposes, the open circuit voltage should be at least 50 to 60 volts and should be adjusted to higher values when required by certain welding conditions. Actual voltage across the arc while welding is not shown accurately by the voltmeter on the welding machine because it measures voltage across the terminals of the machine.

(2) *Current.* In practical arc welding it is impossible to establish a set of current values that can be used satisfactorily under all conditions. Hence, manufacturers of electrodes can only generalize when publishing minimum and maximum current values for a certain size and type of electrode. In actual practice it is not always possible to depend on the meters installed on the welding machine. The operator must learn to determine, by operating the welding equipment, whether he is using the proper current values to produce the desired results with maximum speed and minimum cost. The procedure to follow in estimating the maximum current setting for different size electrodes follow: The amperage selection should be equal to the decimal equivalent of the electrode to be used. The voltage selection should be made by using $1/2$ the decimal equivalent of the electrode. For example, with a $1/8$ -inch electrode, use 125 amperes and 62 volts. Test the current setting by trial and error method on a piece of scrap metal, and adjust the arc amperage and voltage switches until the desired effect is obtained.

d. *Polarity.* As previously mentioned, the polarity in a direct-current circuit always remains the same, and the current always flows through the circuit in the same direction. This is not the case in an alternating-current circuit since the current continually reverses direction in keeping with the changes in polarity at the terminals of the ac generator. For this reason all the information given on polarity will apply to a direct-current circuit.

(1) There was a time when nearly all welding was performed with direct current and bare metallic electrodes. Under these conditions it was found desirable to connect the positive side of the arc to the work and the negative side to the electrode. This applied a greater portion of the heat to the work, since the positive side of the arc releases 65 to 75 percent of the heat. With the electrode connected to the negative side of the arc, the polarity of the circuit was said to be straight. Figure 315 illustrates the hookup for straight and reverse polarity.

(A) REVERSE POLARITY



(B) STRAIGHT POLARITY

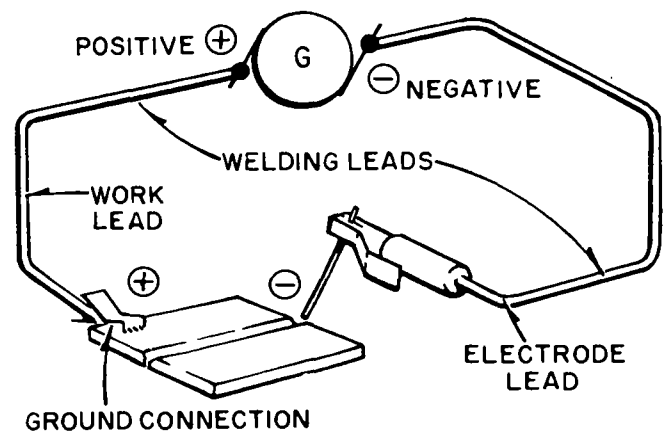


Figure 315. Straight and reverse polarity.

(2) Different jobs require different welding techniques. For instance, when welding cast iron or nonferrous metals, it became important to decrease the amount of heat in the work metal. This was achieved by connecting the work to the negative side and the electrode to the positive. Since the connection had been reversed, the direction of current was reversed, and the welding polarity was said to be reversed, as shown in figure 315.

(3) In the early days of arc welding, it was necessary to change the cable connections at the machine, or at the work and electrode, if a change in the polarity was desired. With the advent of shielded metallic arc welding, the change in the polarity to meet the conditions set up by the different coated electrodes became more frequent. Coated electrodes are manufactured for specific jobs, consequently some of them give better results with straight polarity than reversed polarity, while others produce satisfactory results when used with either polarity.

(4) Manufacturers of welding machines

soon realized that changing the cable connections to change the polarity for each job with different requirements was a cumbersome method. They therefore designed a polarity switch and mounted it on the control panel, making changing polarity a simple, easy, and quick operation.

(5) The polarity to use with a particular electrode is established by the manufacturer. If doubt exists as to the polarity of the welding current at the electrode holder and ground clamp, simple checks can be made.

(6) One method for checking polarity is with a voltmeter. When the voltmeter connection marked positive is connected to the ground lead and the other connection attached to the electrode holder lead, the needle will register the voltage if the leads are connected for straight polarity. If the voltage indicator needle drops below zero, the leads are connected for reverse polarity. Remember that in straight polarity, the electrode is negative.

(7) If a voltmeter is not available, the polarity may be checked with a carbon electrode. Use two carbon electrodes of the same size and shape. Insert one of the electrodes in the electrode holder, establish an arc on a test plate, and run a bead. Change the welding cables and insert the other carbon electrode in the holder, establish an arc, and run a bead.

(8) The carbon electrode used with straight or negative polarity will maintain its shape, the arc will remain stable, and the electrode will not become excessively hot. The electrode used with reverse or positive polarity will have a blunt, burned off end, the arc will be difficult to hold, and the electrode will become excessively hot.

(9) Perhaps the quickest way to determine polarity is to use the E6010 electrode. This electrode is very sensitive to polarity and is designed to be used with dc reverse polarity only. It gives so much better results when used correctly that polarity can be determined by merely observing its performance. When used with straight polarity, the E6010 electrode will emit large volumes of smoke and have an excessive "melt-off" rate.

210. Factors Affecting Welds

In electric arc welding there are several important factors which affect the finished weld and must be considered in obtaining good sound welds. Along with melting the electrode and base metal and their subsequent fusing, the arc has the additional and important ability to dig. This digging quality is referred to as arc force. This is a definite force in the arc stream just as there is in a stream of water flowing from a hose. As water forced through a nozzle will dig dirt,

so can the force of the arc stream be used to dig into the base metal. Each of the most common factors affecting welds is discussed in the following paragraphs and in some instances, they are compared to the flow of water from a hose.

a. *Effect of Current.* An increase in current increases the arc force and penetration just as the increase in the volume of water through the size nozzle increases the digging power of the stream of water. To use higher currents, it may be necessary to use a larger size electrode. Generally, the first indication of an excess of current will be poor surface appearance of the weld.

b. *Effect of Arc Length.* A further comparison of the arc to a stream of water from a hose can be made to arc length. It is obvious that to dig deep into the dirt the nozzle must be kept near the ground to avoid spreading the stream of water into an ineffective spray. When a long arc is held, heat is dissipated into the air, the stream of molten metal from the electrode to the work is scattered in the form of splatter and the arc force is spread over a large area resulting in a wide, shallow bead instead of a narrow one with deep penetration.

c. *Effect of Travel and Speed on Penetration.*

(1) The important factor to observe in the utilization of arc force is causing the arc to travel as a sufficient speed to take advantage of the penetrating power of the arc force. This can be further illustrated by the comparison of water flowing from a hose.

(2) The action of digging away dirt with a stream of water is only effective when the stream is directed at the dirt itself, not when directed into the pool of water which soon accumulates. If the stream of water is to keep digging, it must keep moving fast enough to stay ahead of the pool.

(3) The same reasoning can be applied to welding. When the arc is advanced too slowly, a pool of molten metal forms beneath it, and the force of the arc is expended in the molten pool instead of penetrating into the base metal at the root of the joint. This molten metal flows along the joint under the arc and tends to solidify in the root of the weld without fusing to the base metal.

(4) When the arc is advanced at the proper rate of speed, the arc force digs into the base metal and the result is good penetration. However, at a slow rate of arc speed travel, there is usually a small puddle of molten metal under the arc which dissipates the arc force and prevents maximum penetration.

(5) The degree of penetration is proportional to the current used, combined with the

effective use of the arc force. An increase in current will increase the arc force and penetration. However, if the speed of travel is too slow, the arc force will be wasted and there will still be less penetration than could be obtained by taking full advantage of the force.

(6) In order to effectively use arc force for penetration, the speed of travel should be fast enough so that the electrode tip will be just ahead of the molten pool at all times, giving the arc force full opportunity to dip deep into the root of the joint. The limiting speed is usually the highest speed at which the surface appearance remains satisfactory.

d. Effect of Angularity. The angular position of the electrode to the work is also an important factor to be considered in arc welding. The angle of the electrode may determine to some extent the quality of the weld with freedom from undercutting and slag inclusions. The ease with which the filler metal is placed in the weld and the uniformity of fusion and weld contour as affected by the influence of surface tension and gravity on the molten metal may be the determining factor. The proper angle to use for different types of electrodes in various welding positions can be obtained from the electrode manufacturer.

e. Effect of Arc Blow. Since a magnetic field is set up around any conductor through which electric current is flowing, arc blow is a result of the combined influences of these fields around the arc, the electrode, and the work metal. Arc blow is most likely to occur when welding heavy metal in corners because of the proximity of the sides of the electrode to the metal being welded. Also, arc blow may cause uneven burning of the electrode coating which, in turn, will result in improper fusion. There are a number of methods by which arc blow may be reduced, minimized, or eliminated. Among these are the following:

- (1) Reverse the direction of welding.
 - (2) Weld toward a heavy tack or toward a completed weld.
 - (3) Use back stepping on long welds.
 - (4) Change the position of the ground.
 - (5) Wrap the ground cable around the work several times.
 - (6) Use double grounds, one at each end of the weld.
 - (7) Place ground connection as far from the joint as possible.
- If arc blow is encountered, try these various methods or a combination of methods until a well-behaved arc is achieved.

Note. Check ground connection for security, as a poor ground will sometimes cause fluctuations of the arc quite similar to arc blow.

Arc blow is much less noticeable when welding with alternating current than with direct current. As has been stated previously, this is due to the continuous change in the direction of current flow, resulting in very little magnetic action with alternating current.

211. Thermal and Mechanical Treatments

In some applications welded areas require thermal or mechanical treatment. The thermal and mechanical treatments are necessary to restore the properties of the base metal affected by the heat of the welding arc, to relieve stresses, and to produce the desired structure in the base and filler metal. The use of thermal and mechanical treatment is not required on most welds since the condition of the base metal and filler metal meets the job requirements. However, if any occasion should arise where it is necessary to use thermal or mechanical treatments to bring the welded area up to specifications, consult TM 9-237 for specific information on these treatments.

212. Welding Electrodes

a. Types.

(1) Electrodes are manufactured in a variety of metals and are available for use with any alloy that is classed as weldable by the electric arc welding process. This includes various types of stainless steel, high tensile steels, and manganese steels. Electrodes are also available for welding nonferrous metals and alloys such as aluminum, copper, nickel, and certain types of bronze and brass, some of which were originally considered unweldable.

(2) Electrodes are also manufactured for use with either straight polarity, reverse polarity, or both. They are also designed to be used in the different welding positions; for example, an E6030 electrode is designed for flat welding and is not suitable for vertical or overhead welding positions.

(3) Electrodes are available in a variety of diameters ranging from 1/16 to 3/8 inch and in lengths generally shorter than the rods used in gas welding. Standard lengths are 9, 12, 14, and 18 inches. They are also available in rolls for use in machine welding.

(4) Electrodes are typed according to their coating. There are three main classifications—bare, medium or light coated, and heavy coated electrodes. Each type is discussed separately in the following paragraphs.

b. Bare Electrodes.

(1) Bare electrodes are made of wire containing a definite composition. The surface of the bare electrode has not been treated by the addition of special coatings, other than those materials retained from wire drawing operations. These coatings are required in wire drawings, and their slight stabilizing action on the arc is only incidental. Finished annealed wire is also classified under this type. The bare electrode was the first step forward from the old carbon arc process to the modern methods.

(2) The weld performed with this electrode has a low strength weld deposit as compared to other methods. However, it is still used for training purposes and to a limited extent for welding where it is desired to eliminate the flux deposit and the need for removing the flux after welding. Figure 316 illustrates the transfer of metal cross the arc using a bare electrode.

c. Light or Medium Coated Electrodes.

(1) The surfaces of light or medium coated electrodes have a thin coating of flux applied by a washing, dipping, brushing, tumbling, spraying, or drawing process. This improves the stability and characteristics of the arc stream. These coatings are chiefly iron oxides and titanium dioxide.

(2) In general, these light coatings accomplish the following functions: They dissolve or reduce impurities such as oxides, sulphur, and phosphorous, thereby eliminating or reducing them in the weld deposit. They reduce the adhesive force between the molten metal and the end of the electrode, or change the surface tension of the molten metal so that globules of molten metal leaving the end of the electrode are smaller and more numerous, making the flow

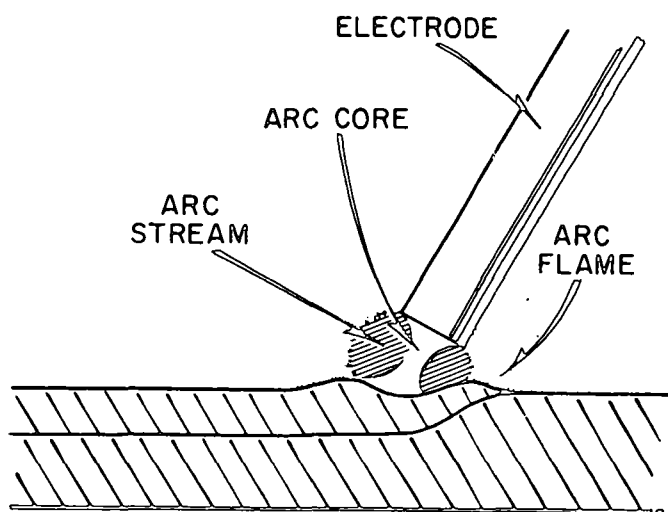


Figure 316. Welding with bare electrode.

of molten metal more uniform and continuous. They also increase the arc stability. Figure 317 illustrates the arc characteristics when using a light or medium coated electrode.

(3) Some of these coatings may produce a slag, but it is quite thin and does not act in the same manner as the shielded arc type electrode slag.

d. Heavy Coated Electrodes.

(1) The surface of heavy coated electrodes is comparatively thick. These coatings have been designed to improve the physical properties of the weld. They also control arc stability and as a result, increase the speed and ease of welding in the vertical and overhead positions. These electrodes are manufactured by the extrusion, wrapping, or heavy dipping processes, or combinations of these methods.

(2) The coatings used on these electrodes consist of two basic materials—mineral coatings and cellulose coatings; however, a combination of the two materials may also be used. The mineral coatings consist of metallic oxides such as clay, feldspar, asbestos, and titanium. The cellulose coatings consist of materials such as wood pulp, sawdust, and cotton.

(3) These heavy coating materials on the electrodes accomplish the following: They produce a reducing or nonoxidizing atmosphere which acts as a shielding medium around the weld deposit, excluding the oxygen and nitrogen of the air. They stabilize the arc and improve the flow of metal from the end of the electrode to the puddle on the work. The coating controls fluidity of the puddle and shape of the bead by providing those ingredients (oxides and silicates) which, when melted, form a slag over the molten metal. This slag, being quite slow to solidify, holds the heat and allows the metal to solidify and cool slowly. This slow solidification allows dissolved gases to escape and permits solid impurities to float to the surface. The slow cooling also has an annealing effect

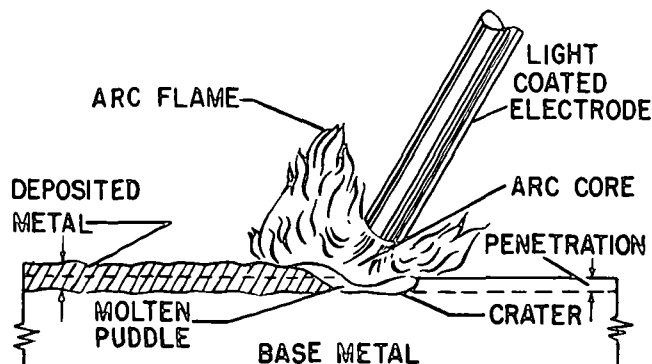


Figure 317. Welding with light or medium coated electrode.

on the weld deposit. Heavy coatings also control the physical properties of the weld deposit and the composition of the deposit by the addition of various metals and alloys to be deposited during the welding process. Figure 318 illustrates the arc characteristics when using a heavy coated electrode.

(4) Coated electrodes should be kept stored in their original containers or in a dry area to prevent the coating from absorbing moisture from the air, especially when the relative humidity is very high. This is especially true of the iron powder and low hydrogen coatings, as an increase in their moisture content will produce unsatisfactory welds. In some cases it is necessary to dry out the electrode coatings by baking the electrodes in a furnace or oven before using them to weld.

e. Classification.

(1) Electrode classification tables are prepared and published jointly by the American Welding Society (AWS) and the American Society for Testing Materials (ASTM). These tables are available in booklet form from either of the above organizations. In order to illustrate these tables, the E60 series classifications are shown in table 56.

(2) As shown in the table, the electrode classifications contain the electrode classification number, type of coating, welding positions, and the recommended current and polarity.

(3) To understand the significance of classification numbers, consider the E6010 classification shown in table 56. The E represents the word electrode. The first two numbers—60—refer to the minimum tensile strength in the stress-relieved condition, or 60,000 psi. The third number explains the possible welding positions, such as "1" for all welding positions (flat, vertical, overhead, and horizontal); or "2," which designates a greater restriction in choice by being

usable only in the horizontal and flat positions; whereas a "3" in the third number indicates that these electrodes may be applied in the flat position only. The fourth number in the classification is used to indicate such things as the proper power supply, quality, type of arc, amount of penetration, etc.

(4) Some electrodes are classified in five-digit numbers instead of four. In this case the first three digits apply to the minimum tensile strength as previously explained for the four-digit classification.

(5) In addition to the electrode classification numbers, iron and steel electrodes may be identified by a standard color code set up by the National Electrical Manufacturers Association (NEMA).

(6) This method of electrode identification employs a two-color system consisting of a primary color located on the end of the electrode and a secondary color located near the top end of the electrode. Figure 319 shows the location of the primary and secondary color markings on end grip and center grip electrodes. Part of the electrode color identification table produced by NEMA is reproduced in table 57.

(1) The first determining factor in the selection of the proper welding electrodes is the type of welding machine being used. If a dc welding machine is being used, it is important to consider the polarity. In some applications it is faster and more economical to use a straight polarity electrode, and there are other applications where reverse polarity electrodes are more satisfactory.

(2) In shops equipped with ac welding machines, only electrodes specified for use with ac welders should be used. In addition to the type of welding equipment being used, there are several other factors which influence the selection of the proper electrode. They are discussed in the following paragraphs.

f. Selection.

g. Type or Kind of Metal to be Welded. This includes different metals such as mild steel, high carbon steel, high tensile steel, stainless steel, cast iron, and any other metal that can be successfully arc welded.

h. Mechanical and Physical Properties Required of the Fabricated Joint. This includes tensile strength, ductility, and hardness or resistance to wear.

i. Welding Position. The four welding positions are flat, horizontal, vertical, and overhead. When welding is done in a flat position, the weld metal can be quite fluid. This results in the best appearing welds and maximum welding

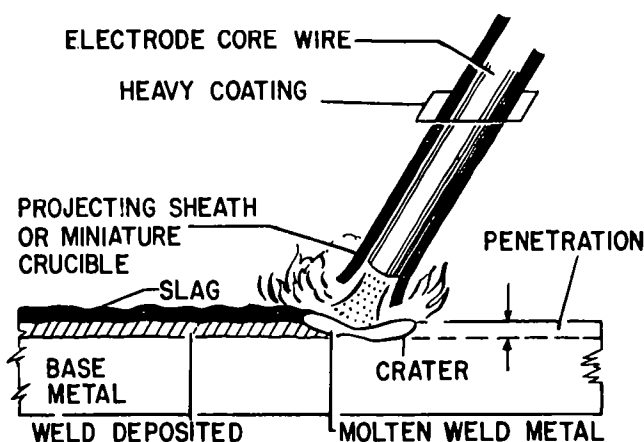


Figure 318. Welding with heavy coated electrode.

Table 56. *Electrode Classification*

AWS-ASTM classification	Type of coating or covering	Capable of producing satisfactory welds in positions shown	Type of current
E60 Series. —Minimum Tensile Strength of Deposited Metal in As-Welded Condition 60,000 psi (or higher).			
E6010	High cellulose sodium	F, V, OH, H	For use with d-c, reverse polarity (electrode positive) only.
E6011	High cellulose potassium	F, V, OH, H	For use with a-c or d-c reverse polarity (electrode positive).
E6012	High titania sodium	F, V, OH, H	For use with d-c, straight polarity (electrode negative), or a-c.
E6013	High titania potassium	F, V, OH, H	For use with a-c or d-c, straight polarity (electrode negative).
E6014	Iron powder, titania	F, V, OH, H	For use with d-c, either polarity or a-c.
E6015	Low hydrogen sodium	F, V, OH, H	For use with d-c, reverse polarity (electrode positive) only.
E6016	Low hydrogen potassium	F, V, OH, H	For use with a-c or d-c reverse polarity (electrode positive).
E6018	Iron powder, low hydrogen	F, V, OH, H	For use with a-c or d-c, reverse polarity.
E6020	High iron oxide	H-Fillets, F	For use with d-c, straight polarity (electrode negative), or a-c for horizontal fillet welds; and d-c, either polarity, or a-c, for flat-position welding.
E6024	Iron powder, titania	H-Fillets, F	For use with d-c, either polarity, or a-c.
E6027	Iron powder, iron oxide	H-Fillets, F	For use with d-c, straight polarity (electrode negative), or a-c for horizontal fillet welds; and d-c, either polarity, or a-c, for flat-position welding.
E6028	Iron powder, low hydrogen	H-Fillets, F	For use with a-c or d-c, reverse polarity.
E6030	High iron oxide	F	For use with d-c, either polarity, or a-c.

The abbreviations F, H, V, OH, and H-Fillets indicate welding positions as follows:

F = Flat	V = Vertical	} For electrodes 3/16 in. and under, except 5/32 in. and under for classifications EXX14, EXX15, EXX16 and EXX18.
H = Horizontal	OH = Overhead	
H-Fillets = Horizontal Fillets		

speed. Horizontal position welding requires electrodes possessing a very forceful penetration so weld metal will reach the root of the joint. Vertical and overhead joints require electrodes having the same characteristics as those used for

horizontal welding. However, because there is an increased tendency of the molten metal to run out, electrodes for this type of welding must also produce a fast-cooling slag.

j. Condition of the Metal to be Welded. It is

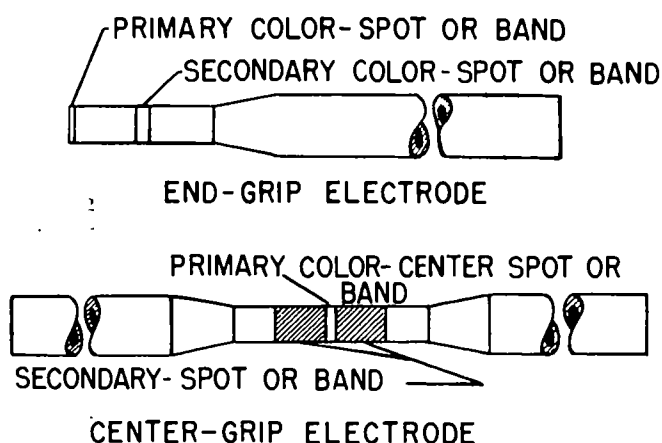


Figure 319. Electrode color markings.

naturally desirable to have all joints as clean and free from grit, rust, and oil as possible. However, when this is not practicable, electrodes possessing characteristics of cleaning action and penetration should be selected. When the welding surface is coated with a plating metal, a strong arc is also necessary. However, a clean joint is always the most desirable.

k. Joint Preparation and Joint Fit Up. The joint influences welding speed and economy, making it desirable that parts fit well. The best electrode for welding a properly prepared joint is the one which affords the greatest speed after meeting the load and stress requirements of the joint. There are many cases, however, where "poor fit up" joints cannot be avoided. Then, an electrode that has excellent "poor fit up" qualities should be used. A "poor fit up" joint should not be confused with a properly spaced Vee joint having a backup strip.

213. Welding Procedures and Techniques

a. Checking Equipment.

(1) The first step in preparing to arc weld is to make certain that all the necessary equipment is available and that the welding machine is properly connected and in good working order. Make certain that all connections are correct and tight. Particular attention should be paid to the ground connection, as a poor connection will result in a fluctuating arc, difficult to control. To make a good contact, the clamp should be cleaned and the point of contact thoroughly brushed.

(2) The electrode is clamped to its holder at right angles to the jaws. Coated electrodes have an end of the electrode free of coating to provide good electrical contact. Handle the

electrode holder with care to prevent accidental contact with the bench or work, as such contact may weld it fast.

(3) Before commencing to weld, the following list of items should be checked off:

(a) Is the machine in good working order?

(b) Have all connections been properly made? Will the ground connection make good contact?

(c) Has the proper type and size electrode been selected for the job?

(d) Is the electrode properly secured in the holder?

(e) Has sufficient protective clothing been provided, and is it in good condition?

(f) Is the work metal clean?

(g) Does the polarity of the machine coincide with that of the electrode?

(h) Is the machine adjusted to provide the necessary current for striking the arc?

b. Setting Up the Welding Machine.

(1) The machine most likely to be found in the welding shop will probably be a dc dual control type, rated at 200 amperes; and therefore this type of machine will be used in our discussion. As previously stated, these units have two controls—one for open-circuit voltage, the other for amperage.

(2) Manufacturers of welding machines use different dial markings, and it is advisable to refer to the manufacturer's operating manual for specific information concerning a particular machine. This manual will furnish the necessary information for adjustment to proper amperage and voltage values necessary for particular jobs. The general procedure, regardless of the machine dial markings, will follow the pattern described below.

(3) After checking the polarity of the machine to make certain that it coincides with the electrode used, set the machine at the highest open circuit voltage within the limits of the job. This makes it easier to maintain the arc. Then set the amperes at the lowest recommended ampere setting, according to the diameter of the electrode. This is the preliminary setting.

(4) Begin the weld at this setting and increase the amperes (heat) and lower the voltage until the arc and the resulting weld are satisfactory. Most welders run an experimental weld until the machine is adjusted to their individual liking. Good welders weld as much by ear as they do by eye, and they judge a good arc by the satisfying frying sound which it makes.

(5) There are a number of variable factors affecting the machine setting. These include size and type of electrode, thickness of metal

Table 57. Color Markings for Electrode Identification

Primary colors					
Spot or secondary color,	Mild steel and low alloys (See Note I)			Special purpose	Hard surfacing (See Note II)
	All position	Horizontal fillets & flat	Flat position only		
	No color	Blue	White		
No color	E6010	E6020	E6030	Mild steel for cast iron	0.40-0.70% Carbon
Blue	E6011				0.90-1.10% Carbon
White	E6012			Cast iron for cast iron	Brinell 200 min
Brown	E6013			0.5-1.0% Ni	Brinell 300 min
Green	E7010	E7020	E7030	2.0-3.0% Ni	Brinell 400 min
Red	E7011			12.0-14.0% Mn	Brinell 500 min
Yellow	E8010 E8011	E8020	E8030	Ni Mn	Brinell 600 min
Black	E9010 E9011	E9020	E9030	Ni Cr Mo	Brinell 700 min
Orange	E10010 E10011	E10020	E10030	Ni Cr Cu	
Violet					
Gray					

Note I: Electrodes listed with prefix letter are AWS designated grades.

Note II: Hardness shall be determined as follows:

- (a) Use a base plate of mild steel 5" square x 1" thick.
- (b) Use 3/16" electrode.

to be welded, type of joint, and skill and technique of the welder. With these variables to be considered, it is apparent that any set of current values could be merely generalization. Current values as published by different manufacturers vary considerably for the same classification and size of electrode.

(6) Table 58, compiled by the American Welding Society, is included for information, but the current values in this chart are merely suggestive. A setting on the welding machine within these ranges should be used only as a preliminary setting since the table is intended to cover all welding positions.

(7) The proper welding current for a given set of conditions can be determined from the degree of electrode heat. If the electrode becomes

excessively hot, it indicates that the current is too high. Welds of good quality cannot be made if the electrode overheats, and in such instances the current must be reduced or the size of the electrode increased. With proper current and electrode, a smooth, uniform bead should result.

c. Preparation of Work.

(1) The strength of any weld may be appreciably affected by lack of proper preparation of the work. Better strength is always obtainable when the work metal is clean and free of foreign matter. It is also highly important that the edges be prepared in a manner that will permit complete fusion without an excessive amount of heat. This is also necessary in order to minimize the amount of heat radiating from the weld to the surrounding base metal.

(2) There are five types of joints used to weld various forms of metal by the electric arc method. These are the butt joint, tee joint, lap joint, corner joint, and the edge joint. The kind of joint, thickness of metal, direction of welding, facilities for preparing the metal, and the load to which the weld is to be subjected govern the preparation of the joint. Figure 320 illustrates the preparation of edge and corner joints for arc welding.

(3) Welds are commonly identified by the kind of joint involved, being referred to as butt welds, lap welds, edge welds, tee welds, and corner welds. Obviously, a so-called butt weld may be of either the bead or the groove type, according to the preparation of the joint.

d. Commencing the Weld.

(1) Striking the arc.

(a) The welding arc is established by touching the plate with the electrode and immediately withdrawing it a short distance. At the instant the electrode touches the plate, a rush of current flows through the point of contact. As the electrode is withdrawn, an electrode arc is formed, melting a spot on the base metal and the end of the electrode.

(b) The main difficulty confronting a beginner in striking the arc is freezing—that is, sticking or welding the electrode to the work. If the electrode is not withdrawn promptly upon contact with the plate, the high amperage will flow through the electrode and practically short circuit the welding machine. The heavy current melts the electrode which sticks to the plate before it can be withdrawn.

(c) Relaxation while welding is important. Gripping the electrode holder too tightly causes the muscles used to control the electrode to be under tension, and the welder tires easily

and loses the control essential to a good weld. To relieve some of the electrode holder's weight, the cable may be draped over the welder's shoulder or coiled in his lap. The holder is usually gripped in one hand which may be supported by the other. You should use the position which is most natural and which suits the position of the job being performed.

(d) The hand gripping the electrode holder, as illustrated in figure 321, is supported by the other hand for added steadiness. Elbows are kept close to the body and the cable is draped over the shoulder—an excellent position for the beginner. When you have learned to control the electrode with both hands and have gained confidence, you should develop the ability to control the electrode with one hand.

(e) There are two essentially similar methods of striking the arc. The first is a vertical up-and-down tapping motion, illustrated in figure 322. While the method is commonly used by experienced operators, it often presents difficulties to the beginner. The second method of striking the arc, illustrated in figure 323 consists of a side-scratching motion of the end of the electrode in which the electrode tip barely grazes the surface of the plate, making contact and establishing the arc.

(f) Regardless of the method used, the electrode must be withdrawn quickly upon contact with the plate so as to provide the gap necessary to maintain the arc.

(g) Try the first, or touch method for striking the arc, as shown in figure 322. Hold the electrode in a vertical position, lowering it until it is an inch or so above the point where the arc is to be struck. Hold it in this position without touching the electrode to the plate, and lower the face shield into position. Touch the electrode very gently and swiftly to the work, using a downward motion of the wrist, and immediately withdrawing it to form a long arc ($1/8$ to $3/16$ inch). Hold the arc for a few seconds, then break it.

(h) To strike the arc by the scratch method, move the electrode downward until it is just above the plate and at an angle of 20° to 25° , as shown in figure 323. Hold it there without touching the plate, then drop the shield to protect the eyes. Strike the arc gently with a swiftly sweeping motion, scratching the electrode on the work with a wrist motion. Immediately withdraw the electrode to form a long arc. Hold the arc for several seconds, then break it.

(i) The purpose of holding an excessively long arc immediately after striking is to prevent the large drops of metal, passing across

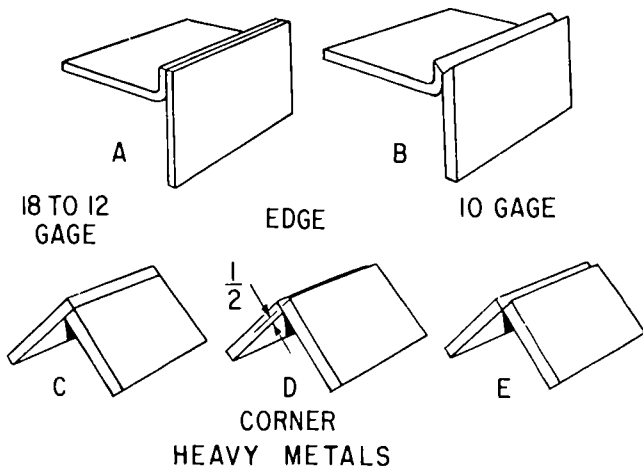


Figure 320. Preparation of edge and corner joints for arc welding. (A) For metals 18 to 12 gage; (B) for 10-gage metals; (C), (D), and (E) for heavier sheet.

Table 58. Typical Current Ranges in Amperes for Electrodes

Table LIX. Typical current ranges in amperes for electrodes.

Electrode diameter, inch	E6010 and E6011	E6012	E6013	E6020 and E6030	E6027	E6014 and E7014	E6015, E6016, E7015, and E7016	E6018 and E7018	E6024, E6028, E7024, and E7028
1/16	...	20 to 40	20 to 40	...	...	...	...	...	...
5/64	...	25 to 60	25 to 60	...	...	...	...	...	...
3/32	40 to 80	35 to 85	45 to 90	...	...	80 to 125	65 to 110	70 to 100	100 to 145 ^a
1/8	75 to 125	80 to 140	80 to 130	100 to 150	125 to 185	110 to 160	100 to 150	115 to 165	140 to 190
5/32	110 to 170	110 to 190	105 to 180	130 to 190	160 to 240	150 to 210	140 to 200	150 to 220	180 to 250
3/16	140 to 215	140 to 240	150 to 230	175 to 250	210 to 300	200 to 275	180 to 255	200 to 275	230 to 305
7/32	170 to 250	200 to 320	210 to 300	225 to 310	250 to 350	260 to 340	240 to 320	260 to 340	275 to 365
1/4	210 to 320	250 to 400	250 to 350	275 to 375	300 to 420	330 to 415	300 to 390	315 to 400	335 to 430
5/16	275 to 425	300 to 500	320 to 430	340 to 450	...	390 to 500	375 to 475	375 to 470	...

^aThese values do not apply to the E6028 and E7028 classifications.



Figure 321. Proper technique for flat arc welding.

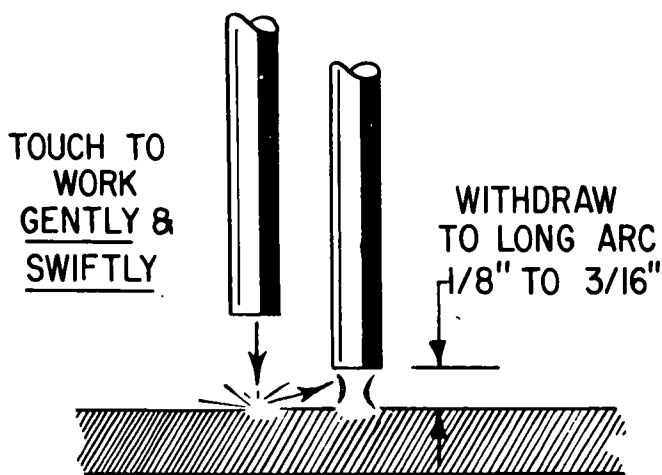


Figure 322. Touch method of starting the arc.

the arc at this time, from shorting out the arc and thus causing freezing. This also helps to more smoothly fuse one bead with the previously deposited bead.

(j) Practice striking the arc until proficiency and skill are attained. After the arc can be struck with ease, hold it long enough to run a bead of about 1/2 inch. Remember that a good arc, with correct current value and length, is characterized by an unmistakable frying sound.

(2) Length of arc.

(a) The distance through the center of the arc from the electrode and to the point where

the arc contacts the metal is referred to as arc length. With coated electrodes, the length is measured from the metallic core rather than the coating because the metallic core may burn away more rapidly than the coating.

(b) Bare electrodes generally use an arc length equal to their diameter. Too long an arc results in poor fusion, excessive spatter, and a contaminated weld. Too short an arc may cause a very porous weld and may include particles of slag. In practice, the arc length will be determined by the kind of electrode, its diameter, position of welding, and amount of current used.

(3) *Maintaining the arc.* The arc is maintained by a uniform continuous movement of the electrode toward the work to progressively compensate for that portion which has been melted and deposited in the weld. At the same time, the electrode is also progressively advanced in the direction of the weld.

(4) *Running a bead.*

(a) A weld is a single bead or a combination of beads, and it is thus important for the arc welder to understand the difference between good and bad beads.

(b) A bead is the metal deposited by one pass of the arc welding electrode. When a weld is made up of more than one bead, it is called a multiple pass weld.

(c) To form a uniform bead, the electrode must be moved along the plate at a constant speed in addition to the downward feed of the electrode. The rate of advance, if too slow, will form a wide bead resulting in overlapping, with no fusion at the edges. If the rate of advance is too fast, the bead will be too narrow and have little or no fusion at the plate. When proper advance is made, no overlapping occurs, and good fusion is assured.

(d) In advancing the electrode, it should be held at an angle of about 5° to 15° in the direction of travel, as illustrated in figure 324.

(5) *Restarting the arc.*

(a) If the arc is broken during the welding of a bead, a crater will be formed at the point where the arc ends. The arc may be broken by feeding the electrode too slowly or too fast, or when the electrode should be replaced. The arc should not be restarted in the crater of the interrupted bead, but just ahead of the crater on the work metal. Then, the electrode should be returned to the back edge of the crater. Figure 225 illustrates the procedure for restarting the arc.

(b) From this point, the weld may be continued by welding right through the crater and down the line of weld, as originally planned.

(c) Every particle of slag must be re-

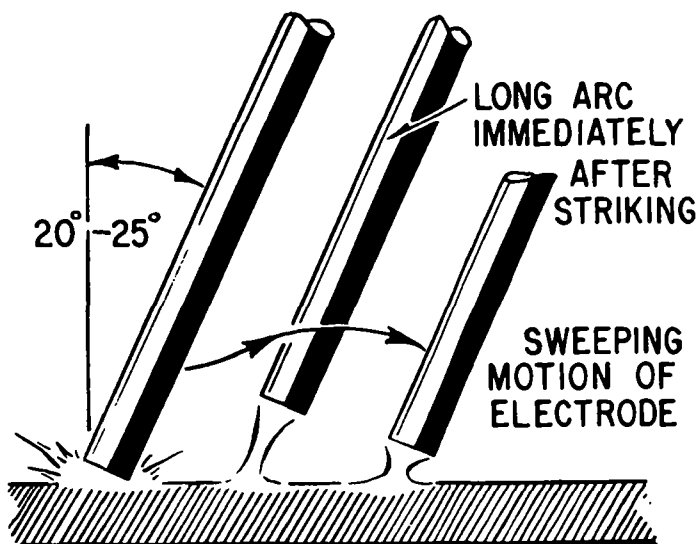


Figure 323. Scratch method of starting the arc.

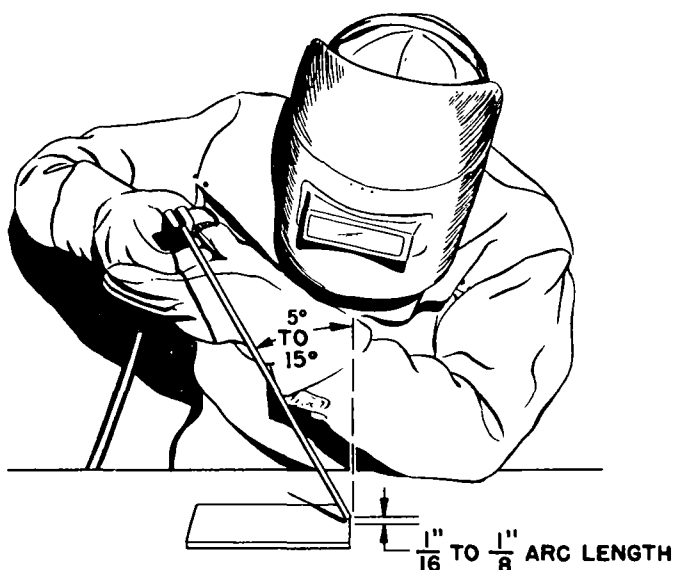


Figure 324. Electrode angle.

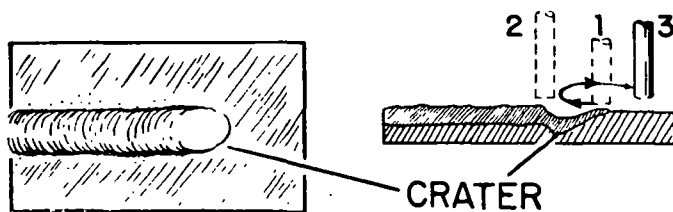


Figure 325. Restarting the arc.

moved from the vicinity of the crater before re-starting the arc. This prevents the slag from becoming trapped in the weld.

(d) After learning to weld straight line beads, it is good practice to weld in one direction to the end of the plate, move slowly to the side, then reverse the direction of travel.

(e) Spend sufficient time on this exercise to become proficient in holding the proper length

of arc and moving the electrode along the plate at the correct speed, so as to secure smooth, even beads.

(f) Study the accompanying chart in table 59. Then continue practicing until you are able to make a weld by the correct procedure indicated.

(6) Weaving technique.

(a) When depositing weld metal, it is often desirable to make the width of the deposit wider than is obtained by depositing a single bead. This is accomplished by a technique known as weaving, or moving the electrode from side to side during the forward motion.

(b) There are number of different weaving motions used in welding, but in all cases it is important that the motion used by uniform. Typical weaving motions are illustrated in figure 326.

(c) If the weave used is not uniform, or close enough, there is danger of poor fusion at the edges and of slag being trapped in the center.

(7) Breaking the arc.

(a) There are two procedures used in breaking the arc. In one, the arc is shortened and the electrode moved quickly sideways out of the crater. This method is used in manual welding when electrodes are changed and the weld is to be continued from the crater.

(b) The other method requires that the electrode be held stationary long enough to fill the crater and then gradually withdrawn. It is used in manual welding when it is desired to minimize or to eliminate the crater.

e. Multiple Pass Welding.

(1) Groove and fillet welds in heavy metals often require the deposit of a number of beads in order to complete a weld. It is important that the bead be deposited in a predetermined sequence in order to produce the soundest welds with the best proportions. The number of beads is, of course, determined by the thickness of the metal being welded.

(2) The sequence of the bead deposits is determined by the kind of joint and the position of the metal. All slag must be removed from each bead before another bead is deposited. This is most important, and will be discussed more fully in the section on joints and techniques of position welding (fig. 327).

f. Specifications for Arc Welds. The specifications which follow are for arc welding required in general maintenance and repair work, such as the manufacture of work stands, storage racks, etc. When welding aircraft parts, approximately the same specifications apply to arc welding as to oxyacetylene welding of these parts.

Table 59. Weld Characteristics

Bead	Operating variables	Arc sound	Resulting weld characteristics		
			Penetration—fusion	Burn-off of electrode	Appearance of bead
A	Normal amperes, normal volts, normal speed.	Sputtering hiss plus irregular energetic crackling sound.	Fairly deep and well defined.	Normal appearance.	Excellent fusion—no overlap.
B	Low amperes, normal volts, normal speed.	Very irregular sputtering, few crackles.	Not very deep nor defined.	Not greatly different from above.	On top of plate—not overlap such as is on bare rod.
C	High amperes, normal volts, normal speed.	Rather regular explosive sounds.	Deep-long crater.	Shielded arc coating is consumed at irregular high rate.	Broad rather thin bead—good fusion.
D	Low volts, normal speed, normal amperes.	Hiss plus steady sputter.	Small.	Coating too close to crater. Touches molten metal & results in porosity. Rod freezes.	Slits upon plate but not so pronounced as for low amperes. Somewhat broader.
E	High volts, normal speed, normal amperes.	Very soft sound plus hiss and few crackles.	Wide and rather deep.	Note drops at end of electrode. Flutter and then drop into crater.	Wide—splattered.
F	Low speed, normal amperes, normal volts.	Normal.	Crater normal.	Normal.	Wide bead—overlap large. Base metal and bead heated to considerable area.
G	High speed, normal amperes, normal volts.	Normal.	Small, rather well-defined crater.	Normal.	Small bead—undercut. The reduction in bead size and amount of undercutting depends on ratio of high speed & amperes.

(1) *Bead weld specifications.* A bead deposited on a metal surface to build it up to a greater height or thickness should be approximately 1 1/2 times as wide as the diameter of the electrode being used. Generally, an inch of bead

length should be deposited for every inch of electrode used. Beads adjoining other beads on the base metal should be fused to one-fifth of their width on either or both sides, depending on the situation.

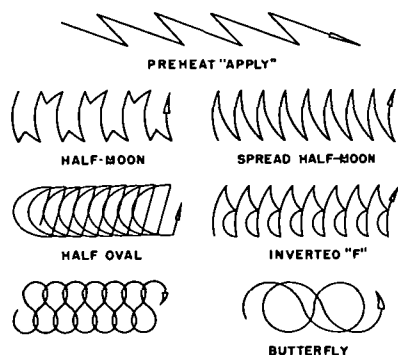


Figure 326. Typical weaving motions.

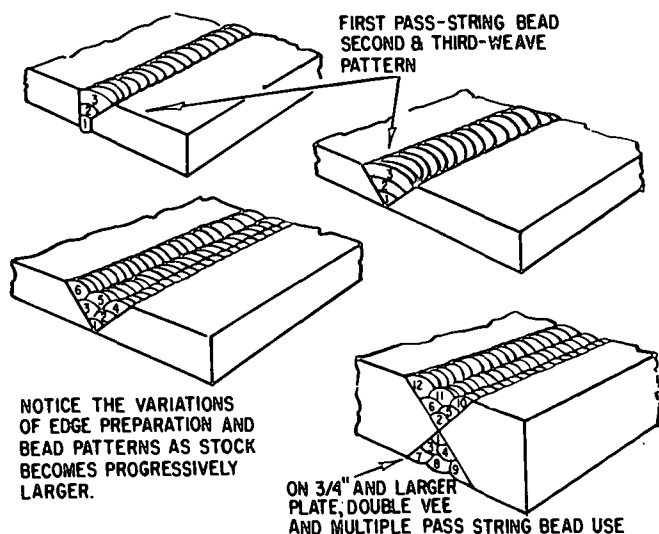


Figure 327. Multiple pass welding of butt joints.

(2) *Groove weld specifications.* The depth of the throat designates the size of a groove weld, whether it be in a butt joint or an outside corner joint. If the plates being welded are of different thicknesses, the thickness of the lighter plate designates the size of the weld. The amount of metal extending above the surface of the base metal is called reinforcement, and it may range from one-thirty-second to one-eighth inch. If the amount of reinforcement is greater than one-eighth inch, the joint will probably concentrate stresses at the edge of the groove, rather than increasing the strength of the joint. On the other hand, insufficient reinforcement fails to develop sufficient strength. The width of a butt weld should be approximately one-eighth to one-fourth inch more than the face of the groove.

(3) *Fillet weld specifications.*

(a) A fillet weld is measured by the length of its shortest leg if the weld has a flat face. If the weld has a concave or convex face, the size of the weld is really designated by the leg length of the largest isosceles triangle which will fit within the cross sectional contour of the weld.

(b) The convex fillet weld causes an uneven distribution of stresses. On the other hand, the concave fillet weld minimizes the abrupt change of contour and gives better stress distribution, but it involves the deposition of excess metal. For most practical applications, the flat fillet weld or the concave fillet weld is used.

(c) The correct size of a fillet weld can be determined most easily by the thickness of the thinnest sheet or plate being welded. The leg of a fillet weld should be equal in length to 1 1/2 times the thickness of the thinnest sheet or plate with the following reservation. When there is a wide variation between the thickness of the metal being welded, it is sometimes advisable to use the average thickness of the sheets. Instructions for using a butt and fillet weld gage are explained in figure 328.

214. Techniques of Position Welding

Each time the position of a welding joint or the type of joint is changed, it may be necessary to change any one or combination of the following: Current value, electrode, polarity, arc length, and welding technique. Current values are determined by the electrode size as well as the welding position. Electrode size is governed by the thickness of the metal and the joint preparation, and the electrode type by the welding position. Manufacturers specify the polarity to be used with each electrode. Arc length is controlled by a combination of the electrode size, welding position, and welding current. As it is impractical to cite every possible variation occasioned by different welding conditions, only the information necessary for the commonly used positions and welds is discussed here.

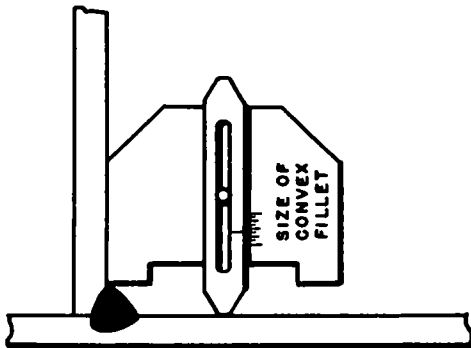
a. *Flat Position Welding.* There are four types of welds commonly used in flat position welding. They are the bead, groove, fillet, and lap joint welds. Each type is discussed separately in the following paragraphs.

(1) *Bead welds.*

(a) Welding a square butt joint by means of stringer bead involves the same techniques as depositing stringer beads on a flat metal surface. Square butt joints may be welded in one, two, or three passes. If the joint is welded with the deposition of one stringer bead, complete fusion is obtained by welding from one side. If the thickness of metal is such that complete fusion cannot be obtained by welding from one side, the joint must be welded from both sides.

(b) When the metals to be welded are butted squarely together, two passes are necessary. If the metals must be spaced, three passes are required to complete the weld. In the latter

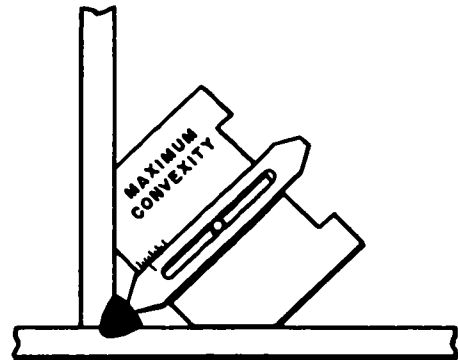
TO DETERMINE THE SIZE OF A CONVEX FILLET WELD



PLACE GAGE AGAINST THE TOE OF THE SHORTEST LEG OF THE FILLET AND SLIDE POINTER OUT UNTIL IT TOUCHES STRUCTURE AS SHOWN.

READ "SIDE OF CONVEX FILLET" ON FACE OF GAGE.

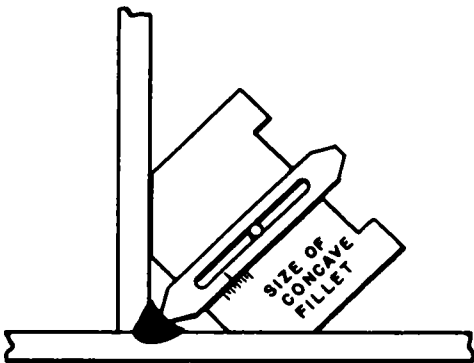
TO CHECK THE PERMISSIBLE TOLERANCE OF CONVEXITY



AFTER THE SIZE OF A CONVEX WELD HAS BEEN DETERMINED, PLACE THE GAGE AGAINST THE STRUCTURE AND SLIDE POINTER UNTIL IT TOUCHES THE FACE OF FILLET WELD AS SHOWN.

THE MAXIMUM CONVEXITY SHOULD NOT BE GREATER THAN THAT INDICATED BY "MAXIMUM CONVEXITY" FOR THE SIZE OF FILLET BEING CHECKED.

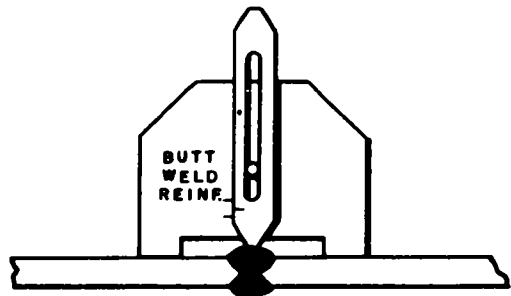
TO DETERMINE THE SIZE OF A CONCAVE FILLET WELD



PLACE GAGE AGAINST STRUCTURE AND SLIDE POINTER OUT UNTIL IT TOUCHES THE FACE OF THE FILLET WELD AS SHOWN.

READ "SIDE OF CONCAVE FILLET" ON FACE OF GAGE.

TO CHECK THE PERMISSIBLE TOLERANCE OF REINFORCEMENT



PLACE GAGE SO THAT REINFORCEMENT WILL COME BETWEEN LEGS OF GAGE AND SLIDE POINTER OUT UNTIL IT TOUCHES THE FACE OF WELD AS SHOWN.

THE PERMISSIBLE TOLERANCE OF REINFORCEMENT IS THAT INDICATED ON THE FACE OF GAGE.

Figure 328. Instructions for using butt and fillet weld gage.

case, the third pass is made directly over the first and completely envelops it.

(c) It must be constantly kept in mind that beads, either the stringer or the weaved type, are used to weld all types of joints. Even though the bead may not be deposited on the same type of surface, its action in the different welding positions and joints is basically the same as its action on the surface of flat metal. The same fundamental rules apply regarding electrodes size and manipulation, current values, polarity, and arc lengths.

(d) Bead welds can be made by holding a short arc and welding in a straight line at a constant speed, with the electrode inclined 5° to 15° in the direction of welding. The proper arc can best be judged by recognizing a sharp cracking sound heard all during the time the electrode is being moved to and above the surface of the plate. Some of the characteristics of good bead welds are: They should leave very little spatter on the surface of the plate. The arc crater, or depression, in the bead when the arc has been broken should be approximately $1/16$ inch deep. The depth of the crater at the end of the bead can be used as a measure of penetration into the base metal. The bead weld should be built up slightly, without any weld metal overlap at the top surface, which would indicate poor fusion. Figure 329 illustrates a properly made bead weld.

(2) Groove welds (butt joint).

(a) Groove welding may be executed in either a butt joint or an outside corner joint. An outside corner joint corresponds to a single vee butt joint, and the same welding technique is used for both. It is for this reason that these two

types of joints are classified under the heading of grooved welding. There are certain fundamentals which are applicable to groove welds, regardless of the position of the joint.

(b) Groove welds are made on butt joints where the metal to be welded is $1/4$ inch or more in thickness. Butt joints with a metal thickness of less than $1/4$ inch require no special edge preparation and can be joined with a bead weld on one or both sides.

(c) Groove welds are classified as either single groove or double groove. This holds true whether the shape of the groove be a V, U, J or any other form. Regardless of the position in which a single groove weld is made, it can be welded with or without a backing strip. If a backing strip is used, the joint may be welded from only one side. When a single groove weld is made without a backing strip, the weld may be made from one side, if necessary, although welding from both sides assures better fusion. The first pass of the weld deposit may be from either side of the groove. The first bead should be deposited to set the space between the two plates, and to weld the root of the joint. This bead, or layer of weld metal, should be thoroughly cleaned to remove all slag before the second layer of metal is deposited. After the first layer is cleaned, each additional layer should be applied with a weaving motion, and each layer should be cleaned before the next one is applied. The number of passes required to complete a weld is determined by the thickness of the metal being welded and the electrode size being used. As in bead welding, the tip of the electrode should be inclined between 5° and 15° in the direction of welding.

(d) Double groove welds are welded from both sides. This type of weld is used primarily on heavy metals to minimize distortion. This is best accomplished by alternately welding from each side—depositing a bead from one side and then from the other. However, this necessitates turning the plates over several times (6 times for $3/4$ -inch plate).

(e) Distortion may be effectively controlled if the plates are turned over twice, as follows: Weld half the passes on the first side, turn the plate over and weld all the passes on the second side then turn the plates over and complete the passes on the first side.

(f) The root of a double groove weld should be made with a narrow bead, care being taken to insure that the bead is uniformly fused into each root face. When a few passes have been made on one side, the root on the opposite side should be chipped to sound metal to make

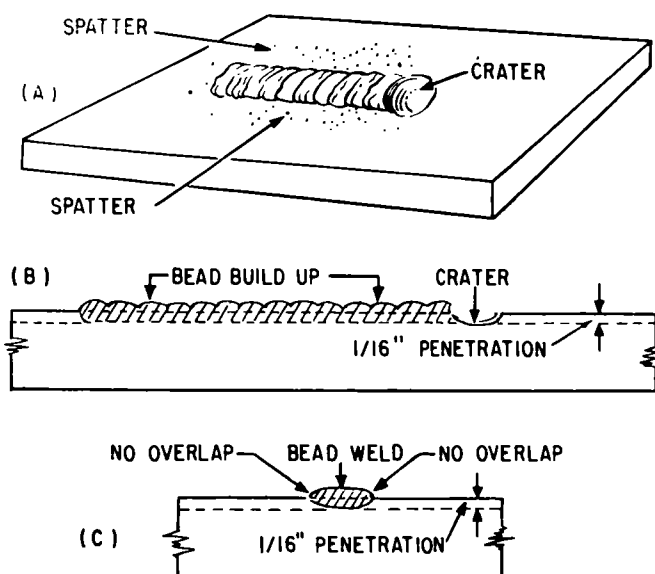


Figure 329. Properly welded bead.

the groove, and then welded with a single bead weld.

(g) Any groove weld made in more than one pass must have the slag, spatter, and oxide carefully removed from all previous weld deposits before proceeding with the weld deposits over them. Figure 330 shows some of the common types of groove welds performed on butt joints in the flat position.

(3) *Fillet welds.*

(a) Fillet welds are used to make tee and lap joints. In welding tee joints in the flat position, the two plates are placed to form an angle of 90° between their surfaces, as shown in figure 331. The electrode should be held at an angle of 45° to the plate surface. The top of the electrode should be tilted at an angle of about 15° in the direction of welding. Light plates should be welded with little or no weaving motion of the electrode, and the weld is made in one pass. Fillet welding of heavier plates may require two or more passes. In that case, the second pass or layer is made with a semicircular weaving motion. In making the weave bead, there should be a slight pause at the end of each weaving motion in order to obtain good fusion to the edges of the two plates without undercutting them.

(b) The procedure for making the lap joint fillet weld is similar to that used for making the fillet weld in a tee joint. The electrode should be held at an angle of 30° to the vertical. The top of the electrode should be tilted to an angle of 15° in the direction of welding. Figure 332 illustrates a typical lap joint. The weaving motion is the same as that used for tee joints, except that the hesitation at the edge of the top plate is prolonged in order to obtain good fusion with no undercut. When welding plates of different thicknesses, the electrode is held at an angle of 20° to the vertical. Care must be taken not to overheat and undercut the thinner plate edge. The arc must be controlled in order to wash up the molten metal to the edge of this plate.

b. *Overhead Position Welding.* The overhead position is one of the most difficult in welding, since a very short arc must be maintained constantly, in order to retain complete control of the molten metal. The force of gravity tends to cause the molten metal to drop down or sag on the plate. If a long arc is held, the difficulty in transferring metal from the electrode to the base metal is increased, and large globules of molten metal will drop from the electrode and the base metal. The transfer of metal is aided by first shortening and then lengthening the arc. However, care should be taken not to carry too large a pool of molten metal in the weld. The proce-

dures for making bead, groove, and fillet welds in the overhead position are discussed in the following paragraphs.

(1) *Bead welds.* For bead welds, the electrode should be held at an angle of 90° to the base metal. In some cases, however, where it is desirable to observe the arc and the crater of the weld, the electrode may be held at an angle of 15° in the direction of welding. Weave beads can be made by using the weaving motion. A rather rapid motion is necessary at the end of each semicircular weave in order to control the molten metal deposit. Care should be taken to avoid excessive weaving. This will cause overheating of the weld deposit and form a large pool of metal, which is hard to control.

(2) *Groove welds (butt joints).*

(a) Overhead groove welds can be made more satisfactorily by using a backup strip. The plates should be prepared in a manner similar to that used for welding butt joints in the flat position. If no backup strip is used and the plates are beveled with a feather edge, the weld will burn through repeatedly, unless extreme care is used by the operator.

(b) For overhead groove welding, bead welds are preferred to weave beads. Each bead deposited should be cleaned, and any rough areas should be chipped out before depositing the next bead. The electrode should not be too large, as this will prevent holding a short arc while obtaining good penetration at the root of the joint. The first pass should be made by holding the electrode at an angle of 90° to the plate. The use of excessive current should be avoided. An excess of current will create a very fluid puddle, making control of the puddle very difficult.

(3) *Fillet welds.*

(a) When making fillet welds on overhead tee or lap joints, a short arc should be held, and there should be no weaving of the electrode. The electrode should be held at an angle of about 30° to the vertical plate, and moved uniformly in the direction of welding.

(b) The arc motion should be controlled to secure good penetration to the root of the weld and good fusion with the sidewalls of the vertical and horizontal plates. If the molten metal becomes too fluid and tends to sag, the electrode should be whipped away quickly from the crater ahead of the weld in order to lengthen the arc and allow the metal to solidify. The electrode should then be returned immediately to the crater of the weld and the welding continued.

(c) Welding on heavy plates requires several passes to make the joint. The first pass is a string bead with no weaving motion of the electrode. The second, third, and fourth passes

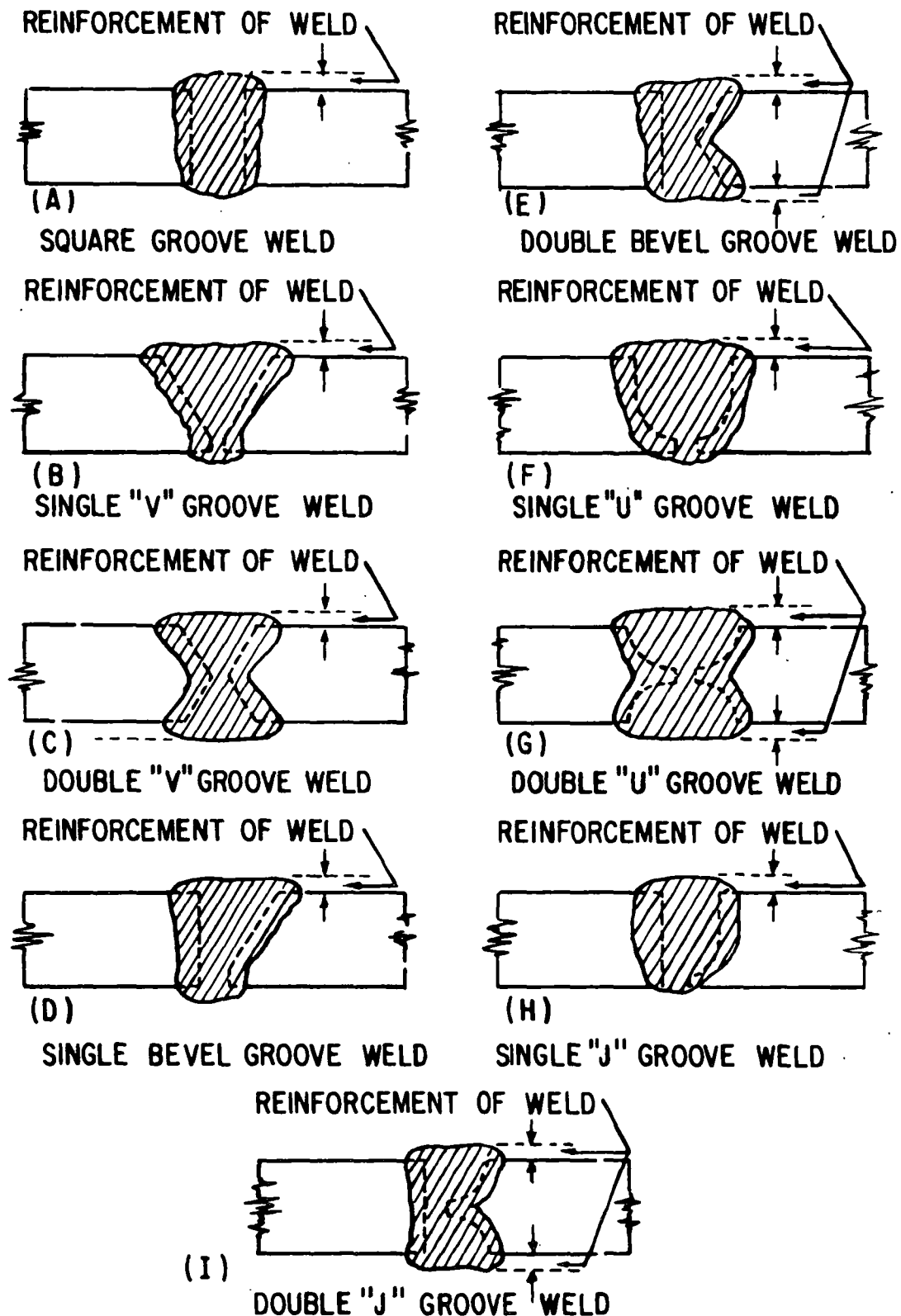


Figure 330. Groove butt joints welded in the flat position.

are made with a slight circular motion of the end of the electrode, while the top of the electrode is held tilted at an angle of about 15° .

c. *Vertical Position Welding.* The vertical po-

sition, like the overhead position just discussed, is also more difficult than welding in the flat position. Due to the force of gravity, the molten metal will always have a tendency to run down.

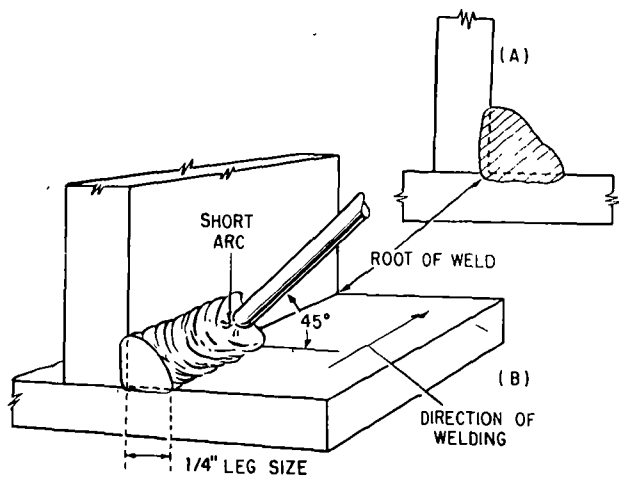


Figure 331. Tee joint fillet weld.

To control the flow of molten metal, a short arc is necessary, as well as careful arc voltage and welding current adjustments. In metallic arc welding, current settings for welds made in the vertical position should be less than those used for the same electrode size and type on welds made in the flat position. The currents used for welding upward on vertical plate are slightly lower than those used for welding downward on vertical plate. The procedures for making bead, groove, and fillet welds in the vertical position are discussed in the following paragraphs.

(1) Bead welds.

(a) When making vertical bead welds, it is necessary to maintain the proper angle between the electrode and the base metal in order to deposit a good bead. In welding upward the electrode should be held at an angle of 90° to the vertical. When weaving is necessary, the electrode should be oscillated with a "whipping up" motion. In welding downward, bead welds should be made by holding the top end of the electrode at an angle of about 15° below the horizontal to the plate with the arc pointed upward toward the oncoming molten metal. When a weave bead is necessary, in welding downward, a slight semicircular movement of the electrode is necessary.

(b) In depositing a bead weld in the horizontal plane on a vertical plate, the electrode should be held at right angles to the vertical. The top of the electrode should be tilted at an angle of about 15° toward the direction of welding in order to obtain a better view of the arc and crater. The welding currents used should be slightly less than those required for the same type and size of electrode in flat position welding.

(2) Groove welds (butt joints).

(a) Groove welding of butt joints in the

vertical position is prepared in a manner similar to that used in welding butt joints in the flat position. In order to obtain good fusion with no undercutting, a short arc should be held, and the motion of the electrode should be carefully controlled.

(b) Butt joints on beveled plates $1/4$ inch in thickness can be groove welded by using a triangular weave motion. In groove welding butt joints in the horizontal position on identical plates, a short arc is necessary at all times. The first pass is made from left to right or right to left with electrode held at an angle of 90° to the vertical plate. The second, third, and if required, any additional passes are made in alternate steps, with the electrode held approximately parallel to the beveled edge opposite to the one being welded.

(3) Fillet welds.

(a) When making fillet welds in either tee or lap joints in the vertical position, the electrode should be held at an angle of 90° to the plates, or at an angle of up to 15° below the horizontal, for better control of the molten puddle. The arc should also be held short to obtain good penetration, fusion, and molten metal control.

(b) In welding tee joints in the vertical position, the electrode should be moved in a triangular weaving motion. The joint should be started at the bottom and welded upwards. A slight hesitation in the weave, as shown in figure 333, will improve sidewall penetration and allow good fusion at the root of the joint. If the weld metal should overheat, the electrode should be lifted away quickly at short rapid intervals without breaking the arc. This will allow the molten metal to solidify without running down. The electrode should be returned immediately to the crater of the weld, in order to maintain the desired size of the weld.

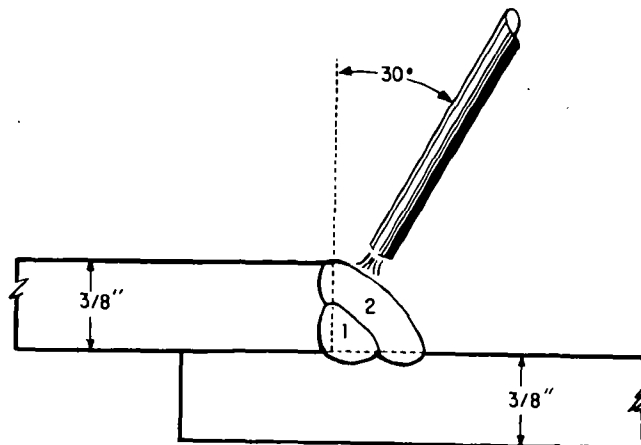


Figure 332. Lap joint fillet weld.

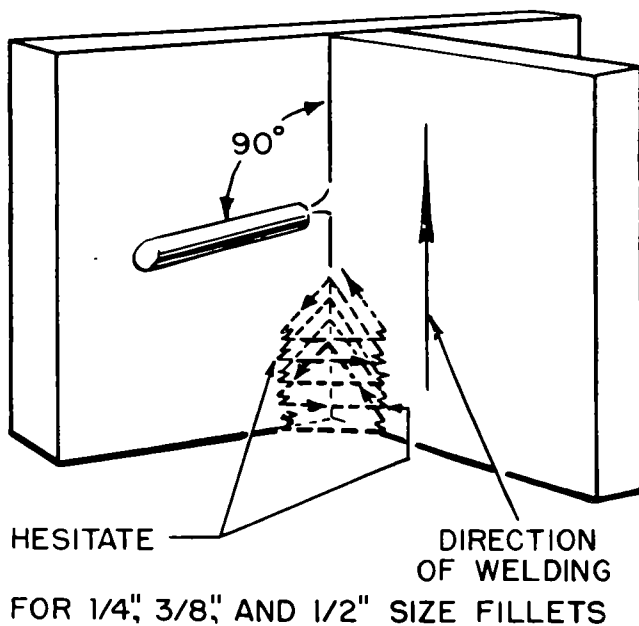


Figure 333. Vertical tee joint fillet weld.

(c) When more than one layer of metal is needed to make a vertical tee weld, different weaving motions may be used. A slight hesitation at the end of the weave will result in good fusion without undercutting the plate at the edges of the weld. When welding lap welds in the

vertical position, the same procedure is followed as that outlined for welding vertical tee joints, except that the electrode is directed more toward the one vertical plate. Care should be taken not to undercut either plate, or to allow the molten metal to overlap the edges of the weave. On heavy plate, lap joints require more than one layer of metal.

d. *Standard Welding Symbols.* The welding symbols shown in figure 334 have been developed and standardized by the American Welding Society. These symbols are used to supply necessary welding information on drawings and blueprints.

215. Safety Precautions

There are numerous safety precautions which should be observed when working with or around electric arc welding equipment. Always make certain that the welding cable and electrode holders are the correct size for the type machine being used, to avoid overheating. The power should be turned off when checking or performing maintenance on the welding machine. Never handle "live" electric lines, even if they are insulated, with wet or oily gloves and always use the safety equipment provided for your protection.

ARC AND GAS WELDING SYMBOLS										
TYPE OF WELD								FIELD WELD	WELD ALL AROUND	FLUSH
BEAD	FILLET	GROOVE					PLUG & SLOT			
		SQUARE	V	BEVEL	U	J				

Figure 334. Standard welding symbols.

Section III. INERT-GAS SHIELDED ARC WELDING

216. General

Inert-gas shielded arc welding is a metal joining development which has become an important welding process, especially for aluminum and magnesium alloys and other hard to weld materials. Essentially, it is a process in which the metal to be joined is united by intense heat from an electric arc between a metal electrode and the work, while the electrode tip, arc, and molten puddle in the weld zone are shielded from the atmosphere by an envelope of inert (chemically inactive) gas, usually helium or argon.

a. There are two major types of inert-gas shielded arc welding. One variation is the tungsten

inert-gas shielded arc welding process, commonly referred to as TIG welding. The TIG process employs a nonconsumable tungsten electrode and is particularly suited for welding thin gage metals less than 1/8 inch thick. The electrode does not burn off or supply metal to the joint. Necessary filler metal is added to the joint, as required, by the operator in a fashion similar to that used in oxyacetylene and carbon arc welding.

b. The second type is metal inert-gas shielded arc welding, commonly referred to as MIG Welding. This process employs a consumable elec-

trode in wire form and is fed continuously and automatically from a spool or reel through a flexible cable to the torch or electrode holder.

c. A specially designed welding machine is used for this type welding. It is a "Constant Voltage" (CV) type of machine. It can be a direct-current (d-c) rectifier or a motor or engine driven generator. The output welding power of this type machine has essentially the same voltage regardless of the welding current. Output voltage is regulated by a rheostat on the welding machine. The range is 15 to 40 volts, depending on the type of shielding gas used (table 60). Open circuit voltage (while not welding) and arc voltage (while welding) are indicated on the machine's voltmeter. The constant voltage machine has no current control; therefore, it cannot be used for manual electrode welding.

d. The special wire feeder and the constant voltage machine is the heart of this process. A fixed relationship exists between the rate of electrode burnoff and welding current. At a

given wire feed speed rate the machine will produce the current required to maintain the arc; consequently, the electrode wire feed rate determines the welding current. Wire feed speed is set by the control knob on the wire feeder. The welding current is indicated on the machine's ammeter (while welding) and ranges from approximately 100 to 800 amperes, depending on the diameter size of the electrode (table 61). Direct current with reverse polarity (DCRP) is used for this process.

e. The MIG welding process uses a consumable electrode wire ranging in size from 0.030 to 1/8 inch. The sizes 0.030, 0.035, and 0.045 are referred to as microwire. The wire is solid and bare, except for a very thin copper coating on the surface to prevent corrosion. It contains deoxidizers to help clean the weld metal and to produce sound, solid welds. The wire should be carefully selected to assure the composition of the wire will have similar mechanical properties as the base metal.

Table 60. Voltage Settings for MIG Welding.

Fillet size "S"	Position	Electrode		Deposit- approx. lb/ft	Gas flow cfh argon	Number of passes	Welding conditions DCRP		Travel-speed ipm
		Size (in.)	Feed (ipm)				Amps	Volts	
1/8"	Flat	3/64	195		36	1	130	20	26
	Horz. & Vert.	3/64	185		40	1	120	20	24
	Overhead	3/64	175		40	1	115	20	24
1/16"	Flat	3/64	260		30	1	195	20	24
	Horz. & Vert.	3/64	235		35	1	170	20	20
	Overhead	3/64	250		40	1	185	20	20
1/4"	Flat	1/16	200		40	1	230	21	21
	Horz. & Vert.	1/16	175		45	1	205	20	20
	Overhead	1/16	175		45	1	205	20	20
3/8"	Flat	1/16	280		45	3	305	22-27	30
	Horz. & Vert.	1/16	175		45	3	205	22-27	25
	Overhead	1/16	195		50	3	235	22-27	25

Table 61. Ampere settings for MIG welding

Material thickness	Electrode		Deposit approx. lb/ft	CO ₂ Gas Flow cfh	Welding conditions DCRP		Reactance	Travel speed ipm
	Size in.	Feed ipm			Amps.	Volts		
18 Ga. - 0.050"	0.045	360	0.010	35	300	26	Yes	190
16 Ga. - 0.062"	0.045	360	0.013	35	325	26	Yes	150
14 Ga. - 0.078"	0.045	360	0.017	35	325	27	Yes	130
1/8"	1/16	200	0.026	35	380	30	No	80
3/16"	1/16	260	0.036	35	425	31	No	75
1/4"	3/32	150	0.077	35	500	32	No	45
3/8"	3/32	205	0.189	35	550	34	No	25
1/2"	1/8	160	0.294	35	625	36	No	23
5/8"	1/8	175	0.411	35	675	36	No	18

f. The distance from the contact tip to the work is called STICKOUT. This distance is controlled by the welder and should be 1/4 to 3/8 inch. The contact tip is recessed from 0 to 1/8 inch inside the cup or nozzle.

g. This process is used primarily for welding low and medium carbon steels, low alloys, and high strength steels of thin and medium thickness.

h. The kind of gas used depends on the metal being welded. Argon is used to weld aluminum and stainless steel, and carbon dioxide (CO) is used for the other steels mentioned above. When CO is used it is referred to as a gas shielded arc welding process rather than an inert-gas shielded process. Carbon dioxide (welding grade) is the most widely used gas and, because of its low moisture content, its flow rate must be between 25 and 50 cubic feet per hour (cfh). In order to maintain this gas flow rate it might be necessary to manifold two cylinders together.

i. The torch receives and guides the electrode wire into a proper position for the welding operation. The wire is fed from the spool or reel through the drive unit and flexible cable to the torch. This cable is independent of the multiple conductor through which the torch receives welding current, gas, and water.

j. The torch is either water or air cooled, depending on the amperage used. Normally the torch is ambient air cooled up to 500 amperes

when CO₂ gas shielding is employed. Figure 335 illustrates MIG welding equipment.

k. The outstanding features of the CO₂ process are: (1) higher welding speed, (2) high metal deposition rates, (3) deep penetration, (4) greater production. The body protection and safety precautions are the same as other types of arc welding.

l. Unlike all other methods of fusion welding, both the TIG and MIG welding processes are capable of making clean, sound welds without the use of corrosive fluxes. This makes the inert-gas shielded processes particularly desirable for aircraft welding. Many assemblies constructed of aluminum, magnesium, titanium, and corrosion-resisting steels cannot be welded by any other method, because of the impossibility of removing fluxes from inaccessible places after welding.

217. Tungsten Inert-Gas Shielded Arc Welding
Tungsten inert-gas shielded arc (TIG) welding is a gas-arc welding process which uses an inert gas to protect the weld zone from the atmosphere. Heat for welding is provided by a very intense electric arc which is struck between a virtually nonconsumable tungsten electrode and the work. The principle of the inert arc is the same as the conventional electric arc discussed in the preceding chapter. The arc is actually the passage of electricity through atmospheric resistance

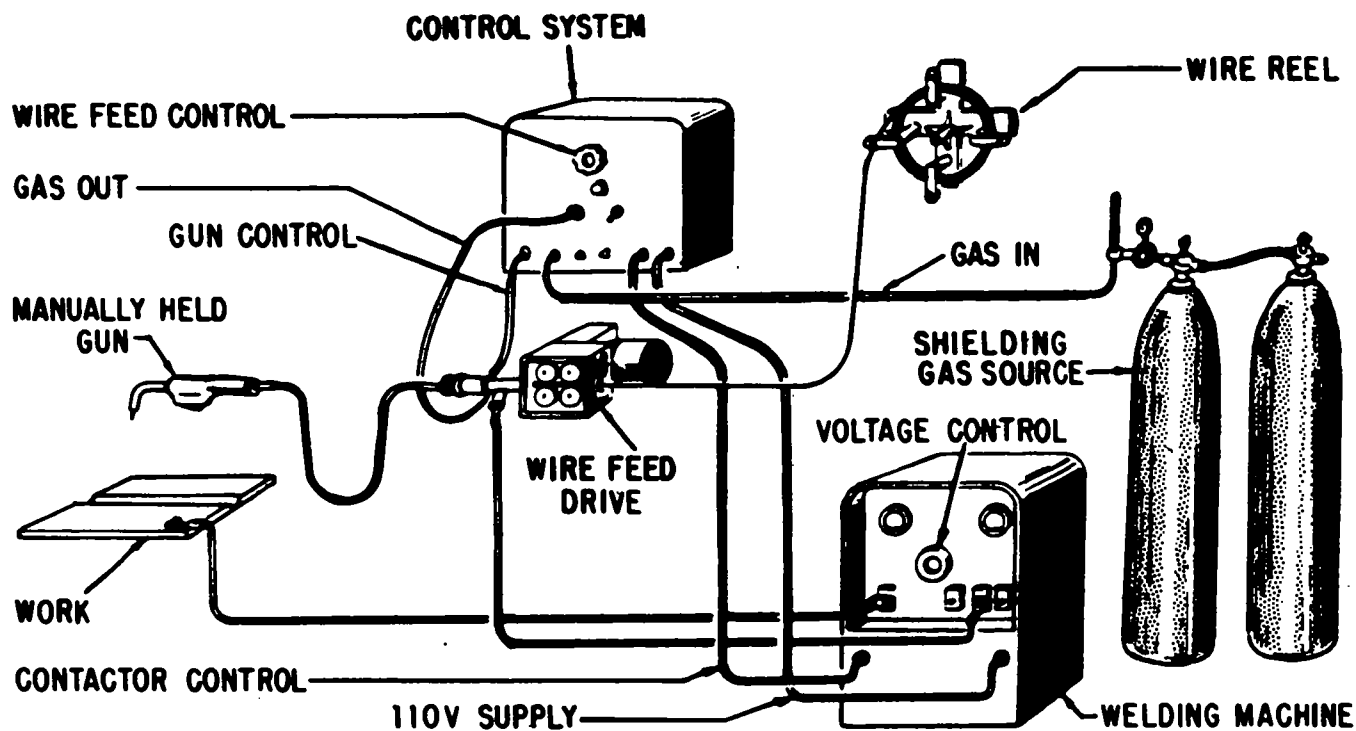


Figure 335. MIG welding equipment.

between the electrode and the bare metal. The current used may be either ac or dc, depending on the material to be welded. This process differs from metallic arc welding in that the electrode is not melted and used as a filler metal. On joints where filler metal is required, a filler rod is fed into the weld zone and melted with the base metal in much the same manner as used with oxyacetylene welding. In any type of welding, the best obtainable weld is one that has the same chemical, metallurgical, and physical properties as the base metal. To obtain these conditions, the molten weld puddle must be protected from the atmosphere; otherwise, atmospheric oxygen and nitrogen will combine readily with the molten weld metal and result in a weak, porous weld. In inert arc welding, the weld zone is shielded from the atmosphere by an inert gas which is fed through the torch. Either of two inert gases may be used, argon or helium. An arc in argon or helium gas is smooth and quiet. In argon the arc has an appearance similar to the oxyacetylene welding flame. In helium the arc is more ball-like in shape. The TIG welding process has several advantages over the conventional arc welding process; and it also has some disadvantages which are discussed in the following paragraphs.

a. Advantages.

(1) Weld are stronger, more ductile, and

more corrosion-resistant than welds made by the conventional arc welding process. The weld zone has 100 percent protection from the atmosphere; therefore, no flux is required. It is applicable to a wider variety of joints and no postweld cleaning is required. Since no flux is required, it eliminates flux or slag inclusions in the weld and there are no sparks, fumes, or spatter. Little or no filler metal is needed.

(2) Efficient use is made of welding current; the machine operates only during actual welding operations, with ac power. Other advantages are high speed, 3 to 12 inches per minute, with a minimum of distortion; efficient use of welding heat; and smooth, even welds with excellent strength and in some cases with only slight reinforcement.

b. Disadvantages. Different types of machines and currents are required for different materials to be welded. For example, alternating current high frequency (ACHF) is used for welding aluminum; while direct current straight polarity (DCSP) is used for heavy gage stainless steel. The initial cost of equipment is high and the gases used are expensive.

c. Application. As previously mentioned, the TIG welding process can be used to weld most metals; particularly the hard to weld metals such as aluminum, magnesium, corrosion-resistant steels, titanium, nickel, and nickel-base

alloys. This process is also used widely for welding various combinations of dissimilar metals, and for applying hard-facing and surfacing materials to steel.

d. Equipment Requirements.

(1) TIG welding equipment is produced by many manufacturers, and there are as many equipment designs as there are manufacturers. For this reason it is very important to remember when studying this chapter that the equipment being discussed is only one of the many types that might be found throughout the Army. However, the functions of similar component parts of different makes of machines are identical although they may not appear to be so.

(2) Basic equipment requirements for TIG welding consist of the torch plus additional apparatus to supply electric power, inert gas, and water (fig. 336).

(3) The torch feeds both the welding current and the inert gas to the weld zone. The current is fed to the weld zone through the electrode which is held firmly in place by the electrode holder. The inert gas is fed to the weld zone through a gas cup which screws on the end of the torch.

e. Power Unit.

(1) The power unit supplies alternating current through a transformer, or direct current through a motor generator. The type of current used depends largely on the material to be welded. The power source for operating a direct-current (d-c) welder can be supplied by any standard motor-driven generator with adequate amperage capacity for the job. Best results are obtained with an open circuit voltage of not more than 80 volts.

(2) For a-c welding power, any standard transformer with an adequate amperage capacity for the job may be used. For best results the open circuit voltage should be from 60 to 100 volts, and the transformer should be a balanced wave type. Regular a-c power for TIG welding should have high-frequency current for stabilizing the welding arc. When high-frequency current is used, a normally open foot or torch switch is recommended to shut off this current before the torch is withdrawn from the weld. This prevents formation of a line arc that, with the gas protection removed, might cause oxidation and crater cracks in the weld metal.

(3) In direct-current welding, the welding

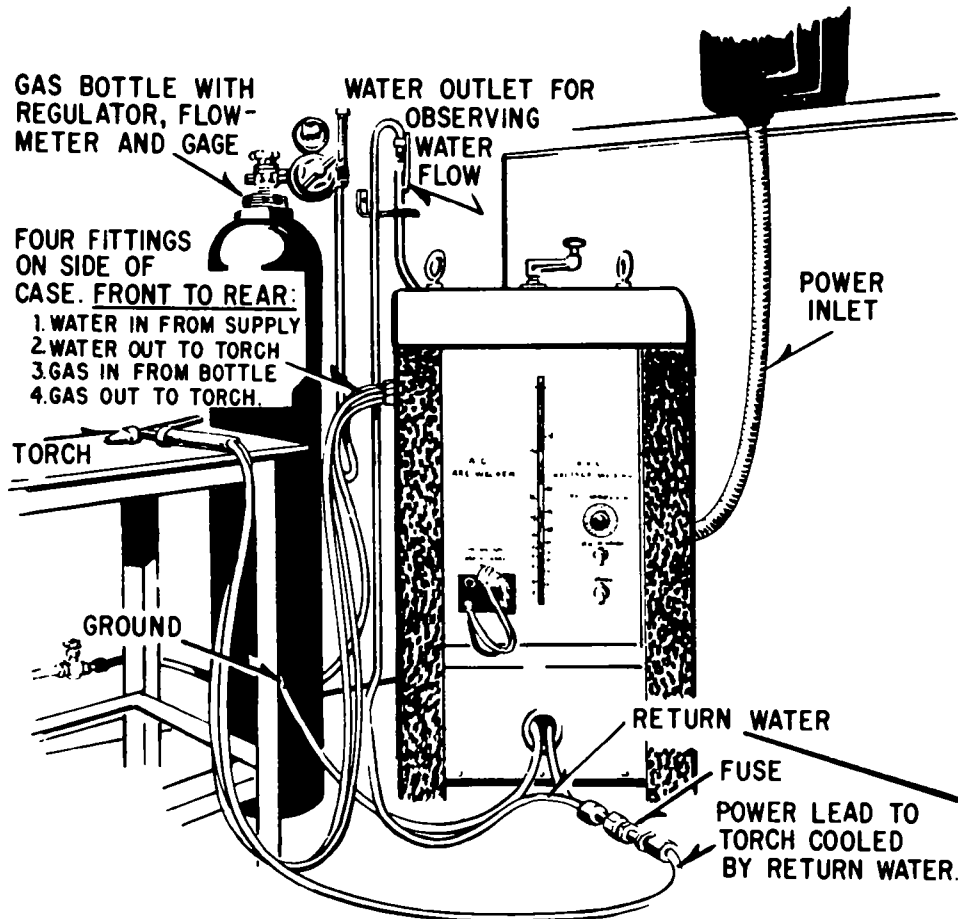


Figure 336. Typical TIG welding equipment.

current circuit can be hooked up as either straight polarity or reverse polarity. The machine connection for direct-current straight polarity welding is electrode negative and work positive. For direct-current reverse polarity the connections are reversed and the electrode is positive and the work negative.

(4) In straight polarity welding, the electrons, hitting the workpiece at high velocity, exert a heating effect on the plate; while in reverse polarity welding, just the opposite occurs. The electrode has to absorb the extra heat, which tends to melt off the end of the electrode. Therefore, reverse polarity requires a larger electrode diameter than straight polarity. For example, a 1 1/16-inch diameter pure tungsten electrode can handle 125 amperes of welding current with straight polarity. If the polarity was reversed, this amount of current would melt off the electrode and contaminate the weld. A 1/4-inch diameter electrode is required to handle 125 amperes of reverse polarity current safely.

f. Hand Welding Torches.

(1) There are various types of TIG welding torches available and, although not all torches have the same external appearance, their principle of operation is much the same. Figure 337 shows a schematic of a typical water-cooled TIG welding torch. The torch illustrated is designed to perform several functions: hold the electrode; introduce an envelope of shielding gas around the electrode; transmit current to the electrode; and circulate cooling water throughout the holder.

(2) The water-cooled torch is designed for TIG welding using either alternating current or

direct current with straight or reverse polarity. Gas enters through a hose fitted to the rear of the handle, passes through the body of the torch, and emerges from the gas orifice in the torch head. Gas is then guided down toward the weld puddle by the shielding gas cup which surrounds the electrode.

(3) Cooling water circulates through the torch and out around the power cable. The water cooling protects parts of the torch from excessive heat and permits the use of a minimum of insulation in the body of the torch. The torch is light and easy to manipulate.

(4) The power cable is contained in the water discharge hose, and is water-cooled in such a manner that extremely high currents can be used without excessive power loss.

Caution: Be sure water lines are hooked up properly. Do not weld with water flow reversed. The water should cool the torch body before it flows over the power cable.

(5) The torch is fully insulated to safeguard the operator against shock, and to prevent damage to the work from accidental arcing. Overheating of the torch, due to failure of the water supply, is prevented by a special fuse inserted in the cable circuit section of the water discharge line. Standard 3-ampere, 250-volt links can be used. Two fuse links must be used to accommodate maximum amperage capacity of the torch. Use of the torch at high amperages tends to deteriorate the shielding gas cup.

(6) Tungsten electrodes for TIG welding are available in three types: pure tungsten (99.9 percent), 1 percent thoriated tungsten, and 2 percent thoriated tungsten. These electrodes have a very high melting point and are practically

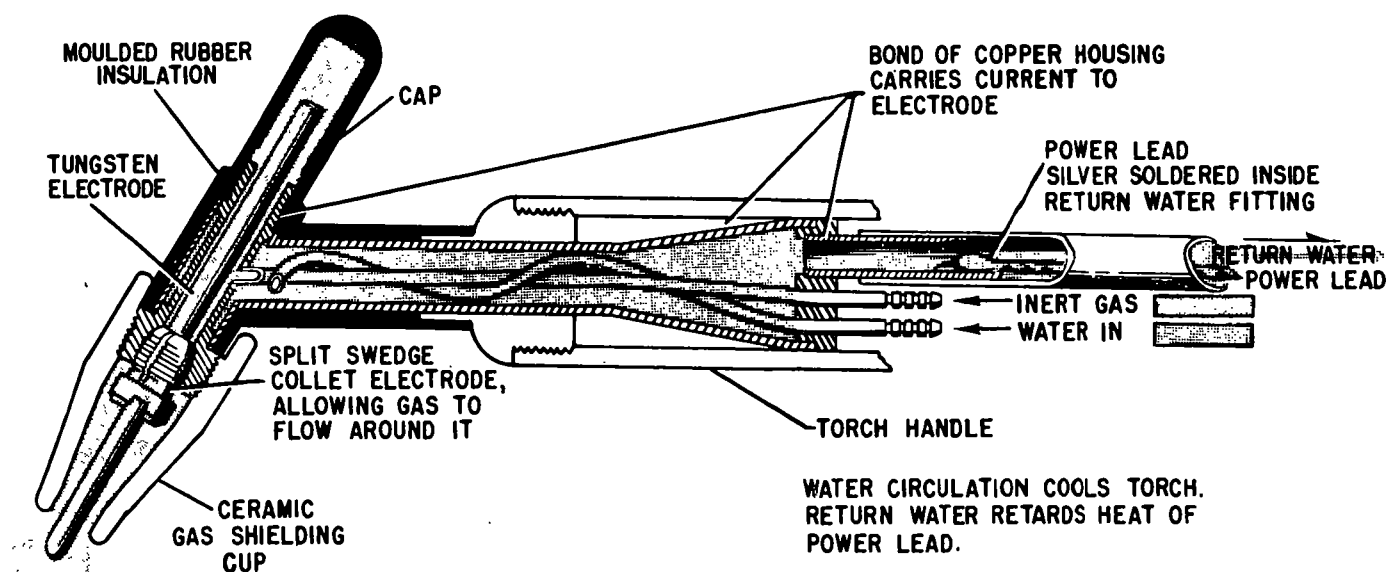


Figure 337. Typical water-cooled TIG welding torch.

nonconsumable—normal consumption is 0.001 to 0.005 inch per hour.

(7) The electrode, particularly in manual operations, will pick up contamination from the work caused in most cases by touching the workpiece. The life of the electrode can be extended by making sure that the electrode does not come in contact with the work during welding operations, and by choosing an electrode of the proper size for the current range being used. The electrode will deteriorate more rapidly when the welding current is too high or too low for the particular size electrode being used.

(8) If the electrode comes in contact with the workpiece or worktable, a small bead or ball will appear at the contact end. This causes the arc to become unstable. This ball may be removed by grooving the electrode just above the fouled point with a file, then breaking it off with pliers. It is essential that the electrode be grooved to prevent splitting when the burned metal is broken off. This operation can be repeated as often as necessary until the electrode can no longer be clamped or held in the torch.

(9) Electrodes are available in 3- to 12-inch lengths and 0.020- to 3/8-inch diameters. The

diameter of the electrode to be used is determined by the current. The current is governed by the type and thickness of the material to be welded. Table 62 gives the recommended current ranges for nonthoriated and thoriated electrodes. The electrodes are held in place by a collet (fig. 337). Electrode length is adjusted by extending or retracting the electrode through the collet clamping device.

Note. Select an electrode which is well within the current range being used.

g. Ceramic and Metal Cups. Ceramic and metal cups are available in various sizes. The type and size of the cup, in most cases, depend on the size of the electrode and the current to be used. Table 63 shows the recommended gas cup sizes for the HW-10 and the HW-18 torches. Ceramic cups are acceptable when the welding current is less than 250 amperes. When higher currents are used, or when welding conditions are usually severe, metal cups are used. Metal cups should never be allowed to come in contact with the workpiece when the current is on.

h. Regulator.

(1) The regulator used on the inert-gas cylinder is identical in design to those used on

Table 62. *Recommend Current Ranges for Nonthoriated and Thoriated Tungsten Electrodes (HW-18 Torch)*

Welding Currents, Amp.				
High-frequency alternating current*		Direct-current straight polarity (Using pure tungsten or thoriated electrodes)	Direct-current reverse polarity (Using pure tungsten or thoriated electrodes)	Electrode diameter (inch)
(Using pure tungsten electrodes)	(Using thoriated tungsten electrodes)			
5-15	5-20	5-20		0.020
10-60	15-80	15-80		0.040
50-100	70-150	70-150	10-20	1/16
100-160	140-235	150-250	15-30	3/32
150-210	225-325	250-300	25-40	1/8

*The maximum current values shown in the table for high-frequency alternating current have been determined using an unbalanced wave transformer. If a balanced wave transformer is used, either reduce the maximum values in the table by about 30 percent or use the next larger size electrode. This is necessary because of the higher heat input to the electrode in a balanced wave setup.

NOTE: All current values are metered readings. Most transformers deliver about 15 percent more current than shown on their scale readings.

Table 63. Recommended Gas Cup Sizes for the HW-10 and HW-18 Torches

Electrode diameter (inch)	Hand Welding HW-10 and HW-18 Torches			
	Ceramic Cups Max. Rating		Metal Cups Max. Rating	
	250 amp. AC-DC		300 amp. AC-DC	
	HW-10	HW-18	HW-10	HW-18
0.020		4-5		4
0.040	4	4-5	4	4-5
1/16	4-5	4-5-6	4-5	4-5-6
3/32	6-7	6-7	5-6	5-6-7-8
1/8	6-7-8		6-7-8	6-7-8-10-12

oxygen cylinders. It is ruggedly built, and combines high sensitivity of control with a large flow capacity.

Caution: Always stand to the side when cracking the cylinder valve. Gage faces sometimes blow out when pressure is suddenly applied.

(2) The function of the regulator is to reduce the high pressure in the cylinder to the desired working pressure, and hold that pressure without fluctuation or readjustment, until the cylinder is almost exhausted. Figure 338 shows a typical regulator, flowmeter, and pressure gage combination.

i. Flowmeter.

(1) Along with pressure reduction, successful inert-gas shielded arc welding requires a constant flow of shielding gas. The gas flow rate

is indicated by a graduated glass tube flowmeter (fig. 338). As shown, the flowmeter is usually attached to the regulator, but it may be installed elsewhere in the gas line. Be sure you have the proper flowmeter for the gas being used or the flow indicated will be incorrect.

(2) Flow is regulated by a needle valve of special design, and is measured by the position of the lightweight metal spinner inside a graduated glass tube. Flowmeters are calibrated in liters per minute (lpm) or cubic feet per hour (cfh). The selection of gas flow is a critical factor. A sufficient flow of gas is required during the welding operation to prevent oxidation of the weld metal. The weld zone must have 100 percent protection from the atmosphere. This flow will be found in the range of 4 to 15 liters per minute for argon, and 8 to 40 liters per minute for helium.

(3) The exact flow setting will depend on the type of joint, fit of the joint, and the material to be welded. Small differences in conditions can make considerable difference in the required flow. The distance the torch is held from the work will change the required flow sharply. A drafty shop will increase the required flow. An increase in welding speed, while generally acting to reduce gas consumption, will usually require an increase in gas flow. The flowmeter should be mounted vertically.

j. Inert Gases.

(1) The inert gases used in the inert-gas shielded arc welding processes are argon or helium. An inert gas is defined as a gas that will

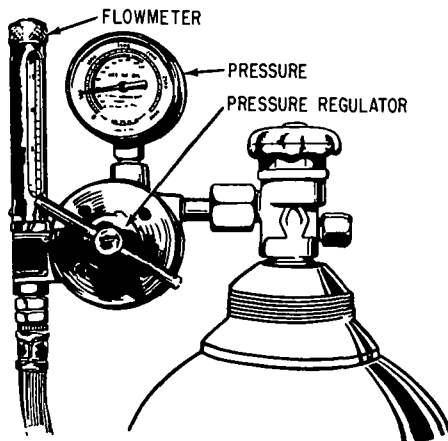


Figure 338. Regulator, flowmeter, and pressure gage.

not combine chemically with any known substance.

(2) Whether the gas used in inert-gas shielded arc welding is helium or argon, the gas must be of high purity and free of moisture, hydrogen, and hydrocarbons. While both argon and helium are used interchangeably, and in some instances have been mixed, each gas has advantages for certain applications.

(3) Argon's density (weight per volume) is considerably greater than that of helium, but it offers less resistance to the passage of electricity than does helium. Because of the difference in electrical resistance, the heat produced by the arc in an atmosphere of helium is hotter than that developed in argon. The helium-shielded arc also produces deeper penetration, but at the same time has a greater tendency to spatter. Because of its greater density, argon remains in the weld vicinity longer and provides a better cleaning action when welding aluminum and magnesium with alternating current. For these reasons, about one-third less argon than helium is needed to provide equal shielding.

(4) Commercial argon has certain advantages over commercial helium in his process; therefore, it is used to a greater extent. Commercial argon is available in 99.8 percent purity, this purity being far above any commercial standard for helium.

(5) The cylinders used for storing argon and helium are similar to those used for oxygen and acetylene. Each cylinder has a 242 cubic-foot capacity, and is charged to approximately 2,200 psi.

(6) Almost pure shielding gas is required in inert-gas shielded arc welding. Since any impurities in the cylinder will have a tendency to settle to the bottom, cylinders should always be replaced when the pressure in the cylinder reaches 25 psi.

(7) Helium is stored in cylinders painted gray with two orange bands at the top. Cylinders containing argon are also painted gray but have one white band at the top. The same care should be exercised in handling, setting up, and storing argon and helium cylinders as those prescribed for oxygen and acetylene cylinders.

k. Water-Gas Shutoff Valves. Shutoff valves for water and gas are of two types, solenoid and manual. The solenoid valve is controlled electrically. The manual valve is shut off by hanging the torch on the hook provided on the valve. A water drain or recirculating system is necessary to carry away the water coming from the cooling system of the torch. Gas should be

permitted to flow after the arc is broken for a minimum of 5 seconds to a maximum of 40 seconds, depending on the diameter of the electrode. The electrode should be brought to a silvery-white appearance, without blue-black discoloration, which indicates oxidation.

l. Protective Equipment. The protective equipment used for inert-gas shielded arc welding is similar to that used in electric arc welding. The operator should be properly protected from the arc rays. This requires suitable clothing to cover all exposed skin surfaces, and a welder's helmet with the skin surfaces, and a welder's helmet with the proper shade of glass to protect the eyes and face. The recommended welding glass numbers for various welding applications are given in table 55.

m. Setting Up and Adjusting Equipment. In most cases TIG welding machines are delivered from the factory ready for installation in the shop. However, they must be set up and adjusted, making it necessary for shop personnel to be familiar with the important units on the machine and the power requirements. The manual supplied with the machine should be consulted in setting up and adjusting the machine. Some of the general requirements are discussed in the following paragraphs.

n. Power Requirements. For alternating-current welding, a single-phase transformer requiring a 220- or 440-volt, alternating-current supply is generally used. The power from the machine to the electrode and work is supplied through two terminals on the machine, marked GROUND and ELECTRODE. Always make certain that the welding cable attached to the torch is connected to the terminal marked ELECTRODE. It is recommended that the welding cables be kept as short as possible to keep the dissipation of the high-frequency current to a minimum. If the welding cables are lying close together, or on a steel plate, the high frequency may in time break down the insulation on the welding cables, thereby weakening the high-frequency output at the welding arc. For direct-current welding, a motor-generator unit powered by a 220- or 440-volt, 3-phase alternating-current supply is generally used. Like the alternating-current machine, two terminals located on the machine supply the power to the torch and work. One terminal is marked POSITIVE and the other NEGATIVE. However, unlike the a-c machine, the torch on the d-c machine may be connected to either terminal, depending upon the polarity to be used. It should be noted, however, that straight polarity is used in almost all cases.

o. Special Control Units. Several special control have been developed to control automatically var-

ious phases of the welding process. Included among these units are a contactor unit which controls gas, water, and power automatically; a unit to shut off the high-frequency power; and a unit to shut off the welding power. These units may be used singly or in combinations, and their use conserves gas and water, reduces radio interference, and provides greater convenience in operation.

p. Water Coolant. The water coolant is required to protect parts of the torch and cable circuit from overheating. The water can run continuously, but it is more convenient to have either a manually controlled valve or an electrically controlled solenoid valve. A solenoid valve can also be used to control the gas and should be connected in parallel with the water solenoid valve. Various torches are designed for different current ranges, and the amount of water required for adequate cooling will vary. To insure that the torch is adequately cooled, always check the manufacturer's specifications for the proper pressure and temperature of the water to be used to cool the torch and cable circuit.

q. High-Frequency Unit.

(1) The high-frequency unit of the TIG welding machine is used to introduce a high-voltage, high-frequency, low-power additional current into the welding current. The high frequency produces a low-intensity arc, which jumps the gap between the electrode and the workpiece and pierces the oxide film, forming a path for the welding current to follow.

(2) Introducing this high-voltage, high-frequency current into the welding current gives the following advantages:

(a) The arc can be started without touching the electrode to the work.

(b) Better arc stability is obtained.

(c) A longer arc is possible.

(d) The tungsten electrodes will have a longer life.

(e) Use of wider current ranges for a specific diameter electrode is possible.

(3) The high-frequency unit of a TIG welder is controlled by a switch located on the front of the machine. Welders which are designed to supply alternating current have a two-position switch. In the OFF position there is no high frequency and in the CONTINUOUS position the high frequency remains on as long as the contactor is depressed.

(4) Welders which are designed to supply either alternating or direct welding current have a three-position switch. The third position is the START position. The START position is used when welding with direct current; high fre-

quency is used in this position only to help start the arc. In the START position the high frequency will shut off automatically as soon as the arc is initiated.

(5) When using the TIG welder for regular arc welding the high frequency is not required, and the switch should be in the OFF position.

(6) The output of the high-frequency rheostat. The highest position provides the greatest high-frequency output and the greatest distance at which the high frequency will establish and maintain an arc from the tungsten electrode to the work. Once the electrode is hot, the jumping distance of the arc from the electrode to the work will increase, as both heat and high voltage ionize the inert gases used in the welding process.

r. Welding Current Controls.

(1) The welding current is controlled by various methods. The current for the TIG welder illustrated in figure 336 is controlled by a handcrank on top of the housing. An indicator, visible through a slot in the front of the machine, indicates the current output.

(2) Other welders have several current ranges which are selected by moving a lever to the desired range. On these machines, current control rheostats are generally used for fine adjustments within the selected range.

(3) The current settings for TIG welding depend on the size of the electrode, speed of travel, thickness of material, and the amount of heat dissipation into surrounding jigs and fixtures.

(4) TIG welders designed to produce both direct and alternating welding current have a current selector. This selector has an alternating-current high-frequency stabilized (ACHF), a direct-current straight polarity (DCSP), and a direct-current reverse polarity (DCRP) position.

Note. On some machines the high frequency is not automatically selected along with the alternating current. On these machines the selector would be set to the a-c position and a manually operated switch would have to be actuated to provide the high frequency.

(5) The type of current used depends on the type of metal to be welded. Alternating-current high frequency (ACHF) is generally recommended for aluminum and magnesium. Direct-current straight polarity (DCSP) is used for all other materials. Direct-current reverse polarity may be used, as needed, when the machine is being operated as a regular arc welder without the use of shielding gas. DCRP is seldom used with TIG.

s. Inspection and Lubrication.

(1) The interior of the welder should be

inspected and cleaned at least once a year. Accumulations of dirt and dust can be best removed by using compressed air.

(2) Occasional lubrication of the threaded shaft and sliding mechanism of the moving coil is essential, especially when the unit is in continuous service. The grease used should have a high melting point and should be evenly distributed on threads of shaft and guides. Use grease sparingly to protect the windings of the coils from lubricating material.

t. Safety Precautions.

(1) There are several general precautions that should be observed when operating TIG welding machines. All adjustments made on the inside of the machine must be in accordance with the maintenance manual for the machine concerned. Make certain that the external power source is shut off since dangerous voltage exists in all parts of the machine unless the power circuit is DISCONNECTED. All protective clothing should be worn and the proper shade lens should be used in the welding helmet.

(2) High-frequency current used in this process can cause deep painful puncture wounds. The operator is more subject to shock when using a-c power. Make certain rubber floor mats are kept in place and the operator remains on the mat at all times when welding.

(3) Insulation on the power lead should be in good condition and the water hose should be checked frequently for leaks. A leaky water hose is very dangerous. Beware of the hazards of hot metal and unsafe equipment. Remember a clean shop is a healthy shop.

u. Welding Procedures and Techniques. Before setting up for a job, make a check on the equipment needed. In general, the items listed below will fill the bill for most jobs.

- (1) A-c or D-c welding machine.
- (2) Inert arc torch.
- (3) Source of running water.
- (4) Source of inert gas.
- (5) Hose.
- (6) Regulator (single or double stage).
- (7) Water flowmeter or visible flow of water.
- (8) Tungsten electrodes of suitable size (polished).
- (9) Gas cups for corresponding sizes of electrodes.
- (10) Protective clothing.
- (11) Leather gloves.
- (12) Head shield with proper shade lens.
- (13) Rubber floor mat.
- (14) Pliers and tongs.
- (15) Clamps, backing plates, or jigs.
- (16) Extra fuses.

(17) Filler rods, if required.

After material and equipment are assembled and set up in a welding booth or curtain area, the next step is to select the right type of current to be used, as shown in table 64. However, it should be kept in mind that figures given in any table in this chapter are to be used only as a basis from which to work. The actual settings for best results can be obtained only through experience.

v. Aluminum and Aluminum Alloys. The TIG welding process is particularly adapted to the welding of aluminum and aluminum alloys. Sound welds may be made without the use of flux. Dispensing with flux is a definite advantage since flux removal from aluminum welded joints is extremely important to avoid corrosion. Although all of the aluminum alloys except 2024 and 7075 are considered weldable by the inert-gas shielded arc process, there are certain restrictions, as described in the following paragraphs.

w. Effects of Welding. The heat of welding decreases the strength of both the nonheat-treatable and heat-treatable aluminum alloys except when the alloy is in the annealed condition. In some cases, the resistance to corrosion is also lowered.

(1) The effects of strain hardening in the nonheat-treatable alloys are partially or wholly destroyed by heat, depending upon the temperatures above 440°F. These alloys are not affected as far as corrosion resistance is concerned.

(2) The effects of solution heat treatment and precipitation treatments for heat-treatable aluminum alloys are adversely affected by the heat of welding. The extent increases with temperature and time at temperature above 400°F. The alloys containing substantial amounts of copper (alloys 2014 and 2017) suffer not only from loss of strength but also from loss in resistance to corrosion when subjected to the heat of welding.

(3) In view of the above, heat-treatable aluminum alloys that have been welded must be properly reheat treated before being used on aircraft. Heat treating after welding dissolves soluble constituents in the weld metal and all of the coarse and fine precipitated particles in the base metal. A more homogenous condition results throughout the material. Quenching retains this solid solution condition while subsequent precipitation, at room temperature or at a moderately elevated temperature when artificial aging is employed, takes place fairly uniformly in the form of finely divided particles. Thus, the maximum strengths and resistance to cor-

Table 64. Selecting the Right Type of Current

Material	High-frequency stabilized alternating current	Direct current	
		Straight polarity	Reverse polarity
Magnesium up to 3/16 inch	1	N. R.	1
Magnesium above 3/16 inch	1	N. R.	N. R.
Magnesium castings	1	N. R.	2
Aluminum	1	N. R.	N. R.
Aluminum castings	1	N. R.	N. R.
Stainless steel 0.015 to 0.050 inch	1	2	N. R.
Stainless steel 0.050 inch and up	2	1	N. R.
High-carbon steel 0.015 to 0.050 inch	1	N. R.	N. R.
High-carbon steel 0.050 inch and up	2	1	N. R.
Cast Iron	2	1	N. R.
Brass alloys	1	1	N. R.
Everdur	2	1	N. R.
Monel	2	2	N. R.
Silver	2	1	N. R.
Hastelloy alloys	1	2	N. R.

1. Excellent operation—first preference.

2. Good operation—second preference.

N. R. —Not recommended.

rosion of the base metal are realized. There is a sacrifice in ductility, however, and the strength of the joint is dependent upon that of the cast material in the weld zone.

Note. Alloys 2024 and 7075 are not fusion welded because of hot cracking and impairment of corrosion resistance. However, both of these alloys are spot and seam welded extensively.

x. Current Requirements. Current requirements for the most commonly used metals are shown in table 65. As shown in the table, first preference for aluminum is high-frequency stabilized alternating current.

(1) The low-intensity arc produced by this high-frequency current provides a path easily followed by the main welding current. The welding arc can be started easily without the electrode actually contacting the work, and a longer arc can be used during welding. With alternating current stabilized in this manner, good welds can be made.

(2) Current range (amperage) depends upon the size electrode, thickness of the metal, and the type of joint to be welded. Table 65 lists the general operating data for aluminum.

(3) *Torch adjustment.* The correct size electrode and corresponding gas cup are selected according to the thickness of the material to be welded.

(4) The electrode should be polished with steel wool before installing it in the torch. Cleaning of the electrode is important since the appearance of the finished weld is improved by the cleanliness of the electrode.

(5) Install the electrode in the torch so that the extension is 1/8 to 3/16 inch beyond the end of the gas cup for butt welding and 1/4 inch for fillet welding. Always make certain that the welding current is off before adjusting the electrode.

Table 65. General Operating Data for Aluminum

Aluminum

Thickness (inch)	Current range (amperes)	Argon flow (cubic feet per hour)	Rod size where required (inches)	Arc speed (inches per minute)
0.025	10-75	10	1/16	10-40
0.031	20-75	10	1/16	10-40
0.0375	35-75	10	1/16	10-40
0.050	50-125	14	3/32	10-40
0.0625	70-130	14	3/32	10-40
0.078	80-150	14	1/8	10-40
0.109	150-175	14	1/8	20-30
0.125	160-200	14	3/16	6-25
0.195	175-200	14	3/16	4-20
0.250	150-200	20	3/16	2-10
0.375	150-225	25	3/16	2-8
0.500	300-450	30	1/4	5-10

(6) *Selection of filler rod.* The selection of the proper filler rod is necessary in order to obtain a weld of high strength and good corrosion resistance. For alloys 1100 and 3003, 1100 filler rod may be used. For other aluminum alloys, 4043, 5154, 5356, or 5456 rod should be used.

(7) *Preparation of metal.* Cleanliness is very important. Parts to be welded should be free of oil, grease, and dirt. Combustible materials in the path of the arc will burn and contaminate the inert-gas shielding. If filler rod is used, it should also be cleaned. Oil or grease should be mechanically or chemically removed. An abrasive disc sander is recommended for mechanical cleaning. Chemical cleaning should be performed, using a caustic bath followed by a sulfuric acid brightening bath. Do not use a wire brush or nitric acid, as this will contaminate the weld.

(8) *Starting the arc.* When alternating current with high-frequency stabilization is being used, it is possible to start the arc without actually contacting the work. Grasp the torch in a comfortable position. Hold the torch in a horizontal position about 2 inches above the work, or starting block, then quickly swing the torch down toward the work or starting block, so that the end of the electrode is 1/8 inch above the work, or starting block. This motion will start the arc. Figure 339 illustrates the procedure for starting the arc. The downward motion should

be made rapidly to provide the maximum amount of gas protection to the weld zone. If the electrode is too far from the work when the arc starts, it will cause oxidation of the weld. In direct-current welding, the same motion is used for starting the arc; however, the electrode must touch the work in order for the arc to start. As soon as the arc is started, withdraw the electrode approximately 1/8 inch above the work to avoid contaminating the electrode in the molten puddle. The arc can be started with a-c or d-c power on the work itself or on a heavy piece of copper or scrap steel and then carried to the starting point of the weld. Do not use a carbon block for starting the arc, as the electrode will become contaminated, causing the arc to wander. In making the first start with a-c power with a cold electrode, the distance the arc will start is much shorter than when the electrode is hot. When starting to weld with a hot electrode, the motions must be rapid, as the arc tends to start before the torch is in the proper welding position. This procedure for starting the arc can be used on all types of materials to be joined by the TIG welding process.

(9) *Breaking the arc.* To stop the arc, merely snap the electrode rapidly back to the horizontal position, as shown in figure 340. This motion is just the reverse of the starting procedure. This motion must be fast so that the arc

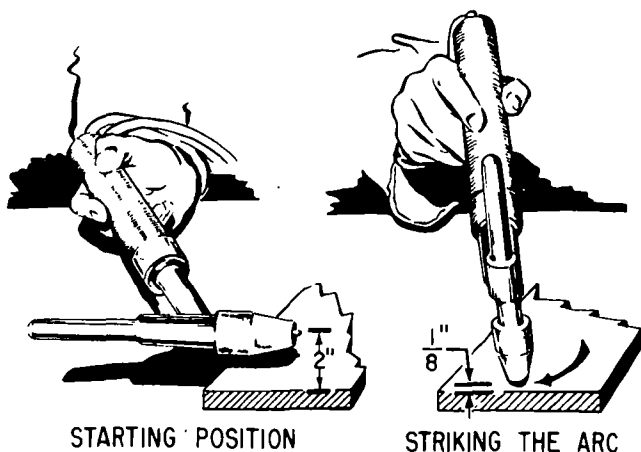
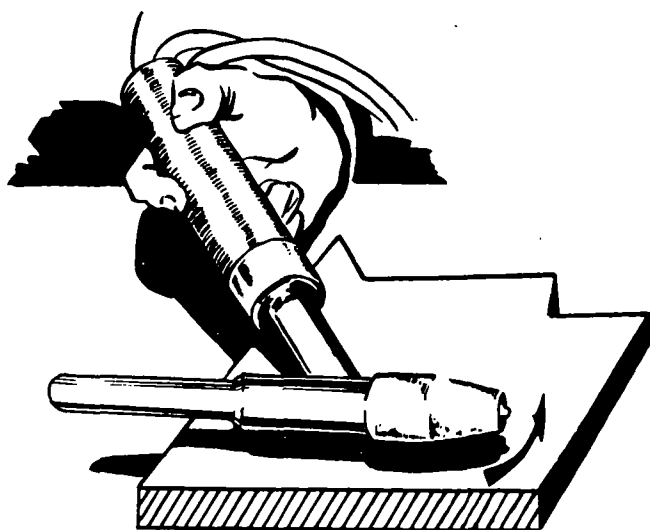


Figure 339. Starting the arc.

will not mar or damage the weld surface or work. When the electrode is hot the arc will jump a greater distance. This procedure for breaking the arc can be used on all types of material.

(10) *Arc blow.* With the torch held stationary, the points at which the arc leaves the electrode and strikes the work may often shift and waver without apparent reason. This is known as arc blow, and is generally caused by one of the following reasons:

- (a) Low electrode current density—amperage for the electrode diameter is too low.
- (b) Carbon contamination of the electrode—caused by starting the arc on a carbon block.
- (c) Magnetic effects—caused usually by improper location of the ground.
- (d) Air drafts—in excessive air drafts, the arc becomes erratic.



BREAKING THE ARC

Figure 340. Breaking the arc.

The first two causes are distinguished by a very rapid movement of the arc from side to side. The third cause will usually displace the arc along the entire length of the weld. The fourth will cause various amounts of arc wandering, depending on how severe the air drafts are.

(11) *Preheating.* It is possible to weld aluminum up to 3/4 inch thick by hand without preheating. However thicknesses over 3/4 inch will require a preheat of 300° to 400°F. By preheating, the operator can work more easily and complete the weld faster. Preheating can be accomplished in special preheat ovens or by gas flames directed on the work in such a manner that they do not disturb the inert-gas shield.

(12) *Welding procedure.* After the arc has been started, hold the torch at an angle of approximately 75° to the surface of the work. The starting point on the work is first preheated by moving the torch in a small circular motion until a molten puddle 3 to 5 times the thickness of the material is developed. The end of the electrode should be held approximately 1/8 inch above the work. When the puddle becomes bright and fluid, move the torch slowly and steadily along the joint at a speed which will produce a bead of uniform penetration and width. No oscillating or other movement of the torch except for a steady motion forward is required. When filler rod is required, the rod is held at an angle of approximately 15° to the work, and just clear of the arc stream. Once the puddle has been developed, move the torch to the rear of the puddle, and add filler rod by quickly touching the leading edge of the puddle. Add only a small amount of rod. Remove the rod and bring the torch back up to the leading edge. When the puddle is again bright, repeat the above steps. Arc speed is governed by the amount of current and thickness of material. Speed should be adjusted to obtain a bead of uniform height and width. The penetration should be uniform on the underside of the work. Good penetration is indicated by a very small, smooth bead. The controlling factors affecting a good weld are as follows:

- (a) Torch angle.
- (b) Arc length.
- (c) Arc speed.
- (d) Electrode condition.
- (e) Joint design.

Some of the precautions to observe when running the bead follow. No attempt to add filler rod should be made until the puddle has been developed. Do not insert the filler rod in the arc stream or considerable spatter and excessive melting of the filler rod will result. Do not attempt to hold the filler rod in the molten puddle.

The amount of filler rod determines the buildup of the bead, and little or no buildup is necessary.

(13) *Inspection of weld.* Inspection of the finished weld is very important not only to make certain that it meets all specifications but also to determine if the proper welding procedures were used. Some possible defects in the weld and their probable causes are:

(a) Bead too narrow—usually indicates an excessive rate of welding speed.

(b) Bead too wide—usually indicates too slow a rate of welding speed.

(c) Weld contamination—indicated by a black deposit on the weld and caused by the electrode coming in contact with the weld metal.

(d) Oxidation of the weld—caused by an insufficient supply of inert gas.

Table 66. Relative Weldability of Magnesium Alloys

Alloy	Form	Arc welding	Remarks
AZ91C	Sand castings.	B	Welding used for repairs and to wrought products.
AZ92A	Sand and permanent mold castings.	C	Welding used chiefly for repairs.
AZ63A	Sand and permanent mold castings.	D	Welding used chiefly for repairs.
AZ81A	Sand and permanent mold castings.	B	Welding used for repairs and to wrought products.
EK30A	Sand and permanent mold castings.	A	Welding used chiefly for repairs and to wrought products.
EK41A	Sand and permanent mold castings.	A	Welding used chiefly for repairs and to wrought products.
EZ33A	Sand and permanent mold castings.	A	Welding used chiefly for repairs and to wrought products.
HK31A	Sand and permanent mold castings.	A	Welding used chiefly for repairs and to wrought products.
HZ32A	Sand and permanent mold castings.	B	Welding used chiefly for repairs and to wrought products.
AZ91A & AZ91B	Die castings.	E	Emergency repair welding only due to porosity.
AZ31B	Extrusions. Sheet.	A A	
AZ61A	Extrusions.	A	
M1A	Extrusions.	A	
AZ80A	Extrusions.	B	
ZK60A	Extrusions.	E	Limited weldability.
HK31A	Sheet and plate.	A	Excellent welding characteristics.

A—Excellent B—Good C—Fair D—Poor E—Very Poor

y. Magnesium Alloys.

(1) *Types that can be welded.* Magnesium alloys in virtually all forms can be successfully welded by the TIG welding process without the use of flux. Since this method requires no flux, all types of joints commonly employed on steel can be used on magnesium.

(2) There are, however, some types of magnesium alloys which have poor weldability and are welded only when emergency repairs are necessary. In table 66 the relative weldability of the standard magnesium alloys is summarized briefly. These weldability ratings are very general, since design, fabrication, and serviceability factors dictate the choice of alloy.

(3) *Current requirements.* Both direct-current reverse polarity and alternating current with high-frequency stabilization can be used for TIG welding of magnesium alloys. The selection of either a-c or d-c power for welding magnesium alloys is largely dependent upon the thickness of the material to be welded.

(4) Direct-current reverse polarity is suitable for thin materials. On heavier sections, multi-pass welding is required in most cases due to shallow penetration. Alternating current with high-frequency stabilization is recommended for the welding of magnesium greater than 3/16 inch in thickness. Table 67 contains the general operating data for magnesium.

(5) *Torch adjustment.* The proper size electrode and corresponding gas cup is determined by the thickness of the material to be welded. The electrode extension should be the same as that previously given for aluminum and aluminum alloys.

(6) *Selection of filler rod.* Magnesium alloy filler rod is used and should be of the same chemical composition as the material being welded. It is necessary to use the recommended filler rod for best results. Filler rod is available in a variety of alloys and diameters. Select the correct diameter rod according to the thickness of the material to be welded.

Table 67. Data for TIG Welding of Magnesium

Material thickness (inches)	Number of passes	Welding current* in amperes		Electrode diameter (inches)		Welding rod diameter (inches)	Gas flow (cu ft/min)	
		AZ31B	M1A	a-c	d-c		Argon	Helium
0.040	1	35	45	3/32	3/32	1/8	0.2	0.4
0.064	1	50	60	3/32	1/8	1/8	0.2	0.4
0.081	1	65	80	1/8	1/8	1/8	0.2	0.4
0.102	1	85	100	1/8	3/16	1/8	0.3	0.5
0.128	1	100	115	1/8	3/16	5/32	0.3	0.6
0.188	1	140	160	3/16	5/16	5/32	0.3	0.6
0.188	2	100	100	1/8	3/16	5/32	0.3	0.6
0.250	1	180	200	3/16	3/8	3/16	0.3	0.8
0.250	2	115	125	1/8	1/4	5/32	0.3	0.6
0.375	1	250	270	3/16	—	3/16	0.4	0.8
0.375	2	140	160	3/16	5/16	3/16	0.3	0.8
0.500	2	310	330	1/4	—	3/16	0.4	0.8
0.750	2	420	450	5/16	—	1/4	0.6	1.2

*Current values given for welding with a backing plate and for making fillet welds. Slightly lower current values used for welding without a backing plate and for making corner or edge joints.

(7) *Preparation of metal.* Cleaning of magnesium is necessary before welding, and can be accomplished by either chemical or mechanical means. For chemical cleaning, a solution of chromic acid and sodium nitrate can be used. Mechanical cleaning can be accomplished with steel wool, abrasive cloth, or a power-operated wire brush. Edges to be welded should be smooth and free from loose pieces or pits which might contain any contamination such as oil, grease, or dirt.

(8) *Welding procedure.* The same method recommended for starting and stopping the arc previously discussed in the section on aluminum can be used on magnesium. The average arc length should be 1/8 inch when using helium and 1/16 inch or less when using argon. A short arc length must be used to produce a bright, shiny weld. Longer arcs will leave the weld surface dark and cloudy in appearance. To obtain maximum penetration with a-c power, the electrode should be flush or slightly below the surface of the work. Accidental touching of the surface with the electrode will not tend to cause it to stick as in the welding of other metals.

(a) The torch should be held with the electrode perpendicular to the work and the filler rod as nearly parallel with the weld surface as possible. The weld should progress in a straight line along the weld seam at a uniform rate of speed so that an even bead is deposited. A weaving or rotary motion is not recommended.

(b) The filler rod can be fed either continuously or intermittently. To avoid oxidation, the rod should not be withdrawn from the inert-gas shield during welding. The end of the rod should touch the leading edge of the puddle. As the torch is moved along, small bits of the rod melt off. No dipping motion of the rod is necessary. With alternating current in welding magnesium, it is desirable to start and stop the arc with a torch switch or open foot switch to prevent oxidation caused by drawing a long arc.

(9) *Stress relieving.* After welding, magnesium should be stress relieved. The temperature for stress relieving varies from 265° to 500°F., depending on the alloy. The soak time also varies from 15 minutes to 1 hour, depending on the alloy. The soak time also varies from 15 minutes to 1 hour, depending on the alloy. When stress relieving, avoid overheating.

(10) *Inspection of welds.* All welds should be inspected for penetration and defects. Improper penetration is indicated by a first line on the reverse side of the weld. This condition can be prevented by slightly beveling the underside of the pieces to be welded. The bevel will let

molten weld metal float away oxides formed by heat as it flows down between the sheets. If cracks appear at the ends of a weld, try preventing recurrence by butting pieces of the same material as that being welded against each end of the joint, clamping them in place until the weld is completed.

z. *Corrosion-Resistant (Stainless) Steel.* The wrought stainless steels are of three principal types: austenitic, martensitic, and ferritic. In aircraft work, the repairman will not be concerned with the martensitic and ferritic steels; therefore, the discussion here is limited to the austenitic types. Austenitic steels are used extensively in aircraft where strength or resistance to corrosion at high temperatures is required. Austenitic steels contain both chromium and nickel and are nonmagnetic. The minimum content of chromium is 16 percent and of nickel, 7 percent. The 18 percent chromium and 8 percent nickel composition is the most popular example of this class of steels. Types 302, 303, 304, 316, 321, and 347 are probably the most extensively used 18-8 steels. All of the above stainless steels can be satisfactorily welded by the TIG process. The one serious difficulty encountered is intergranular corrosion of the metal in or alongside the weld in certain of these steels. When an 18-8 stainless steel with more than 0.08 percent carbon is heated between 1,000° and 1,500°F., the excess carbon is precipitated or segregated out of solution and deposited along the grain boundaries in the form of carbides. These carbides are less resistant to corrosion than is the parent metal. In making a weld, the metal deposited and the joint itself are heated to the melting or fusing temperature, which is approximately 2,690°F., while the body of the work remains cold. Hence, there is a zone parallel to and near the weld which is heated between 1,000° and 1,500°F. It is in this area that carbides are precipitated. This region may be wide or narrow; near or some distance from the weld, depending upon the type of joint and method of welding. If welding is rapid, the zone will be narrow and close to the weld; if slow, it will be wide and farther away. This carbide can be put into solution again by heating to a temperature of approximately 1,900°F. or higher and cooling fast through the critical range. Table 68 lists the recommended postweld heat treatments for the most commonly used austenitic steels. It should be noted that alloys 304L, 316L, 321, and 347 require no postweld treatment. Alloys 304L and 316L have a lowered carbon content (0.03 percent maximum), alloy 321 has titanium added, and alloy 347 has columbium added. When either of these procedures is employed,

the steel is virtually free from intergranular attack.

(1) *Current requirements.* Either direct-current straight polarity or high-frequency sta-

Table 68. Recommended Postweld Heat Treatments for Austenitic Stainless Steels

Stainless Steel

Thickness (inch)	Current range (amperes)	Argon flow (cubic feet per hour)	Rod size (inches) (where required)	Arc speed (inches per minute)
0.025	20-40	10	1/32	15-40
0.031	20-40	10	1/32	15-40
0.0375	50-130	10	1/16	15-40
0.050	80-165	10	1/16	15-40
0.0625	90-170	10	1/16	15-40
0.078	125-200	10	3/32	15-40
0.109	140-250	10	3/32	10-35
0.125	150-275	10	1/8	10-30
0.195	100-225	10	1/8	-----
0.250	400-500	10	3/16	12-20
0.375	400-500	10	3/16	*7-14
0.500				

* 2 passes.

Table 69. General Operating Data for Stainless Steels

AISI Type	Recommended heat treatment
301 302	Cool rapidly from 1,950° — 2,100° F when corrosion conditions are moderate to severe.
304	Cool rapidly from 1,850° — 2,000° F only when corrosion conditions are severe.
304L	Not required for corrosion resistance.
316	Cool rapidly from 1,950° — 2,100° F only when corrosion conditions are severe.
316L	Not required for corrosion resistance.
321, 347	Not required for corrosion resistance.

bilized alternating current may be used in welding stainless steels by the TIG process. Slightly greater penetration and welding speed can be obtained with direct current, and high-frequency alternating current has a tendency to cause hot tearing or stress cracks in or near the weld. Direct-current straight polarity is therefore considered first preference. Table 69 lists the general operating data for welding the austenitic stainless steels.

(2) *Torch adjustment.* The proper size electrode and corresponding gas cup is determined by the thickness of the material to be welded. The electrode should extend about 1/8 inch below the gas cup in most applications. It is important to select the correct size as it is difficult to start and maintain the arc with an oversized electrode.

(3) *Selection of filler rod.* Filler rods for general-purpose welding usually have the same composition as the base metal. Strips cut from parent metal may be used in some cases. For maximum strength and corrosion resistance, a special type filler rod must be used. Detail information on these special types of filler rods can be found in specification MIL-R-5031B.

(4) *Preparation of metal.* As will all other materials to be welded with this process, corrosion-resistant steel must be clean. Parts to be welded must be free from oil, grease, or dirt. The surface to be welded may be cleaned either by chemical or mechanical means as previously discussed in this chapter.

(5) *Welding procedure.* After starting the arc, the torch should be held at an angle of approximately 75 degrees to the work to run the bead. When filler rod is used, it should be held at an angle of approximately 10 degrees to the work. The length of the arc should be approximately 1/8 inch. The procedure for manipulating the torch is basically the same as that used for other materials. The puddle is developed and the rod is dipped rapidly in and out of the forward edge of the puddle. Care must be taken not to pull the filler rod too far from the puddle. A cold filler rod chills the puddle and makes it difficult to maintain. Dipping in and out of the puddle rapidly will assure the addition of filler metal at a uniform rate to form a weld with good contour.

(6) *Weld-backup.* For TIG welding applications on corrosion resisting steels, the joint should be backed up. On light gage materials, backing is used to protect the underside of the weld from atmospheric contamination which results in poor surface appearance. On heavier materials, it prevents the weld puddle from dropping

through by drawing away some of the heat. Some of the materials used for weld-backup are: metal backup bars; inert-gas shielding; a combination of metal backup bars and inert-gas shielding; and fluxes. On applications where the final weld composition must conform to rigid specifications, extra care must be taken to exclude all atmospheric oxygen from the underside of the weld. There are a number of gases and methods of applying them that will give 100 percent protection of the weld zone.

(7) *Inspection of weld.* Good weld penetration is indicated by either the oxide deposit (color bands) or a small smooth bead on the underside of the work. A finished weld should have a regular bead pattern and may require some cleaning. Cleaning can usually be accomplished by wire brushing.

aa. Titanium

(1) Titanium and some titanium alloys can be joined by inert-gas shielded arc welding and resistance welding. Oxyacetylene and metal arc welding with coated electrodes are impractical.

(2) It is very important in TIG welding titanium that the root of the titanium weld, as well as the face of the weld, be protected from the air. This is accomplished with inert-gas backup shielding or, in certain cases, by placing a water-cooled copper bar flush against the underside of the weld joint.

ab. Current Requirements. The recommended power supply for TIG welding titanium is direct current straight polarity. The negative electrode operates cooler than the positive weld joint, enabling a small electrode to carry high current densities. This results in the deepest weld penetration and narrowest bead width.

(1) TIG welding with direct-current reverse polarity requires greater operator skill and generally is not recommended because the hotter electrode increases the possibility for tungsten contamination of the weld. A larger electrode operating at lower current would run cooler, but would produce wide weld beads at the expense of penetration.

(2) High-frequency stabilized alternating current has been used in some cases with apparently similar penetration and strength as that obtained with d-c power, but the uniformity of the welds has never been good.

(3) The TIG process is the most widely used method for welding titanium. It is used almost exclusively on sheet materials up to thicknesses near 0.125 inch. It also can be employed successfully over a wide range of the heavier plate sizes.

(4) TIG welding can be accomplished with

or without filter materials. The decision to use filler is based on the metal thickness and joint fit-up. With good fit-up, filler is generally required for thicknesses near 0.090 inch to avoid undercutting adjacent to the weld bead. With less satisfactory joint fit-up, filler may be required in lighter gages to avoid burn-through as well as undercutting.

(5) Thoriated tungsten electrodes are recommended for welding titanium. These electrodes produce greater arc stability, exhibit superior arc starting characteristics, and operate cooler for a given current density than pure tungsten electrodes. Cooler operating temperatures permit use of smaller electrodes and greater freedom from weld metal contamination.

(6) Proper selection of electrode size is based on the smallest diameter which can carry the required current for a given joint.

(7) This concentrates the heat to insure weld penetration, arc stability, narrow weld beads, and high welding speeds. Generally, a 1/16-inch diameter electrode is satisfactory for the entire range of titanium sheet gages. Center-

less ground electrodes give the best arc-starting characteristics as well as control of the physical dimensions or spread of the arc. Thoriated electrodes retain their points longer than the other types.

(8) The electrode should be centered in the nozzle to provide the arc zone with uniform gas shielding. Extension of the electrode below the nozzle is generally 1 1/2 times the electrode diameter for butt-welded joints. In the case of fillet welds, the electrode is sometimes extended as much as 1/2 inch below the nozzle to retain the larger diameter nozzle required for titanium.

ac. Inert-gas Shielding. The inert gas for shielding titanium may be either helium or argon, a combination of both, or a mixture of both. Helium-shielded arcs operate at somewhat higher arc voltages for a given weld current and are hotter than argon-shielded arcs. This produces greater weld penetration and allows faster welding speeds. However, the hotter helium-shielded arc is also less stable than the argon arc, requiring more operator skill and more accurately controlled weld settings, as well as better joint fit-up

Table 70. Typical Data for TIG Welding Titanium

Tungsten arc without filler

Metal thickness	0.030	0.060	0.090
Electrode diameter	1/16	1/16	1/16-1/32
Voltage	10	10	12
Amperes	25-30	90-100	190-200
Nozzle (ID)	9/16-5/8	9/16-5/8	5/8-3/4
Primary shield (cfh, argon)	15	15	20
Trailing shield (cfh, argon)	20	30	50
Backup shield (cfh, helium)	4	4	5
Backup material	Copper or steel	Copper or steel	Copper or steel
Electrode travel (ipm)	10	10	10
Power supply	DCSP	DCSP	DCSP

to prevent burn-through and weld irregularity.

(1) Argon is generally preferred as the gas in TIG welding. Speed is not the important factor, and more can be gained with a stable arc and the heavier blanket of shielding gas.

(2) Combinations of the two gases involve using argon at the face of the weld and helium on the underside to take advantage of their respective densities and arc characteristics. Mixtures of the two gases are sometimes used for the primary shielding from the nozzle to produce arc characteristics of both helium and argon.

ad. Welding Procedure. Although proper equipment is the first prerequisite for the successful welding of titanium, the use of proper

techniques is of primary importance. These techniques consist of observing certain precautions which would be recognized as optimum practice for the TIG welding of any metal, and include good joint fit-up, clean weld surfaces, and complete protection from atmospheric contamination regardless of the type of titanium welding performed. Additional techniques are dependent upon the particular application and involve the proper selection of joint design, shielding setup, electrode type, and weld machine settings such as current, welding speed, filler wire feed, arc length, and gas flow rate. Recommended settings for welding titanium sheet without filler are listed in table 70.

CHAPTER 13

AIRCRAFT PLASTICS

Section I. GENERAL

218. Plastic Industry

a. The plastic industry began about 1870 when a young American, searching for a new material for billiard balls, developed a material which he called celluloid. Approximately 30 years later, a German found that it was possible to develop a substance with plastic characteristics by mixing formaldehyde and sour milk. Then, in 1909, a synthetic resin substance was developed by an American, Dr. Leo Baekeland. It was a mixture of phenol and formaldehyde and was called Bakelite. Since these early discoveries, research has found ever-widening applications to meet the growing needs of industry.

b. During the pioneering days of the plastic industry, the outstanding characteristics of this new nonmetallic material was its ease of molding. Nearly all of the early-day plastics were molded. However, today a large percentage of the plastics we know and use are cast, machined, rolled, laminated, or formed by other methods.

219. Plastic Groups

According to their chemical sources, plastics

may be classified into four general groups—natural resins, synthetic resins, protein plastics, and cellulose plastics.

a. *Natural Resins.* Natural resins include such materials as shellac, pitch, amber, asphalt, and resin. These materials require fillers when molded.

b. *Synthetic Resins.* Synthetic resins are made from petroleum, glycerol, indene, calcium-cyanamide, benzene, urea, ethylene, phenol, and formaldehyde. Products made from synthetic resins include acrylic plastics, nylon, vinyl, styrene, polyethylene, urea-formaldehyde, and others.

c. *Protein Plastics.* Protein plastics are manufactured from a variety of agricultural products. Sources included are peanuts, cashews, milk, coffee beans, and soy beans.

d. *Cellulose Plastics.* The cellulose plastics are the oldest of the group and include celluloid. Other plastics which fall into this class are acetate, nitrate, ethyl cellulose, butrate, and propionate.

Section II. TRANSPARENT THERMOPLASTICS

220. General

Transparent thermoplastic materials are originally hard but become soft and pliable when exposed to heat. When pliable, the plastic can be molded; and, as it is allowed to cool, it will retain the molded shape. When heated again and allowed to cool without being restrained, the plastic will return to its original shape. This process can be repeated many times without damage to the material unless the specified heat ranges are exceeded.

221. Types and Identification

Two types of thermoplastics commonly employed in windows, canopies, and similar transparent inclosures of aircraft are the acrylic plastics and the cellulose acetate base plastics. Acrylic plas-

tics are used for transparent inclosures on cargo- and combat-type aircraft. Cellulose acetate base plastics are used in some trainers and other non-combat-type aircraft. Cellulose acetate base plastics must not be used as a substitute for acrylic plastics because of their inferior qualities with respect to strength, resistance to weather, freedom from warpage, and transparency. Care must be exercised, therefore, in properly identifying the original and replacement or repair material. The following methods may be used for this purpose:

a. *Military Specification Number.* The identity of transparent plastics used on aircraft may be determined by the Military Specification number on the part. Common Military Specification

numbers and the types of material are listed in table 71.

Table 71. Common Military Specification Numbers for Plastics

Military Specification No.	Type of material
MIL-P-6886	Regular acrylic plastic
MIL-P-5425	Heat-resistant acrylic plastic
MIL-P-8184	Craze-resistant acrylic plastic
MIL-P-14118	Cellulose acetate base plastic

b. Burning. Both acrylic and cellulose acetate base plastics have characteristic odors. Burn a small sample of the questionable material and compare the odor with a known sample. This should be done by igniting the known sample and the questionable piece of material and letting them burn for several seconds. Blow out the flame and immediately check the odor. The acrylic odor is fairly pleasant, but the cellulose acetate odor is very repulsive. Acrylic plastics burn with a steady, clear flame while cellulose acetate base plastics burn with a sputtering flame and dark smoke.

c. Visual Inspection. Upon viewing the light transmitted through the edge of a questionable piece of plastic, acrylic plastics will appear colorless while cellulose acetate base plastics will appear relatively dark, and may have a slight bluish cast.

d. Flexing. Acrylic plastics are more rigid than cellulose acetate base plastics, and hence are harder to bend. In attempting to establish the identity of an unknown material in this manner, it is best to use a known piece of equal size and thickness for comparison.

e. Chemical Reaction. Plastics may also be identified by the application of acetone and zinc chloride. Wet the finger with a solution of acetone and rub it on an area of plastic where it will not interfere with vision. Then blow on the

area. If the plastic is acrylic, it will turn white; if it is cellulose acetate base, it will soften but will not change color. A drop of zinc chloride placed on a piece of cellulose acetate base plastic will turn it milky, but it will have no effect on acrylic plastics.

222. Storing and Handling Precautions
Transparent thermoplastics will soften and/or deform when heated sufficiently; therefore, storage areas having high temperatures must be avoided.

a. Plastic sheets should be kept away from heating coils, radiators, hot water, and steam pipes. Storage should be in a cool, dry location away from fumes (such as may exist near paint spray and paint storage areas).

b. Paper-masked transparent plastic sheets should be kept indoors. Direct rays of the sun will accelerate deterioration of the masking paper adhesive, causing it to cling to the plastic and making removal difficult.

c. Plastic sheets should be stored, with the masking paper in place, in bins which are tilted at approximately a 10° angle from the vertical to prevent buckling. If it is necessary to store sheets horizontally, care should be taken to avoid chips and dirt getting between the sheets. Stacks should not be over 18 inches high, and the smaller sheets should be stacked on the larger ones to avoid unsupported overhang.

d. Masking paper should be left on the plastic sheets as long as possible. Care should be exercised to avoid scratches and gouges which may be caused by sliding sheets against each other or across rough or dirty tables.

e. Formed sections should be stored so that they are amply supported and there is no tendency for them to lose their shape. Vertical nesting should be avoided. Protect formed parts from temperatures higher than 120°F. (49°C.). Protection from scratches may be provided by applying a protective coating.

Section III. TRANSPARENT ACRYLIC THERMOPLASTICS

223. Forming Procedures and Techniques

a. General.

(1) Transparent acrylic plastics become soft and pliable when heated to their respective forming temperatures. They can then be formed to almost any shape; and on cooling, the material retains the shape to which it was formed, except for a small contraction. It is not desirable to cold form compound curvatures using transparent acrylic plastics (that is, to spring them into a curved frame without heating).

(2) Acrylic plastics may be cold bent (sin-

gle curvature) if the material is thin and radius of curvature to which it is to be bent is at least 180 times the thickness of the sheet. Cold bending beyond these limits may eventually result in tiny fissures, called crazing, appearing on the surface of the plastic because of stresses being imposed beyond those recommended for continuous loading.

b. Heating for Forming.

(1) Prior to heating, remove all masking paper and adhesive from the sheet of plastic. If sheet is dusty or dirty, it should be washed and

rinsed well with clean water. Dry thoroughly by blotting with soft, absorbent paper.

(2) For best results in forming, acrylic plastics should be heated to the temperatures shown in table 72. A forced-air oven similar to the one shown in figure 341 should be used. The oven should be capable of operating over a range of 120° to 374°F. (49° to 190°C.).

Caution: If forming temperatures are exceeded during forming of acrylic plastics, bubbling on the surface may occur. In addition, overheating will impair the optical qualities.

(3) For uniform heating, it is best to hang the sheets of plastic vertically. This can be accomplished by an overhead monorail mounted in the roof of the oven and equipped with a spring channel or a series of clips for grasping the plastic sheet as shown in figure 341.

(4) For small pieces which are inconvenient to handle, and for pieces out with insufficient trim to which the clips or channels can be clamped, shelves or drawers are provided. Shelves, covered with soft felt or flannel, should be of open-work construction to assure maximum circulation of air around the sheet of plastic for uniform heating.

(5) Care should be exercised when handling pieces of plastic to avoid finger-marking or otherwise damaging the soft surface. Cotton gloves should be worn when handling plastics.

(6) The air distribution should be uniform over the entire surface. Such an arrangement necessitates filtration of any fresh air which is admitted to the oven. In an emergency, any available oven, such as a kitchen baking oven, may be used.

(7) Other less desirable means may be employed for heating transparent acrylic plastics prior to forming. For example, infrared lamps may be used. They are usually arranged on 7- to 8-inch centers in a bank sufficiently large to cover the maximum size sheet involved. The sheet should be placed approximately 18 inches from the face of the lamps to obtain even distribution of the radiant heat. In general, any method other than oven-heating is undesirable and should be used only in emergencies.

Caution: Do not use hot water or direct steam to heat acrylic plastics, as they may cause the acrylic plastic to become milky or cloudy.

c. Forms. Since most forms used for forming transparent acrylic plastics are subjected to no great pressure, they may be made of material as brittle as plaster. For simple two-dimensional shapes, metal, pressed wood, or plywood forms are easily made. For more complicated shapes, reinforced plaster or plastic forms are easier to make and are perfectly satisfactory.

(1) Forms should be free of waviness and other variations in contour which might cause optical distortion in the formed part. Form surfaces should be sanded smooth and covered with soft cloth such as billiard felt, outing, flannel, flannelette, imitation chamois, or flocked or suede rubber sheeting.

(2) If the final dimensions of the formed parts are critical, the molds must be made sufficiently oversize to allow for shrinkage of the parts when they cool from the forming temperature to room temperature. Mold surfaces should extend beyond the trim line. The form should have some means for holding the edges of the acrylic plastic sheet against the form during cooling.

(3) It is often possible to make forms from plaster, using the broken panel itself as a mold in which to cast the plaster. The broken panel is taped together securely and its inside surface well is greased with vaseline or soap. Sand is packed around the outside surface to give adequate support while the plaster is poured and allowed to set.

d. Methods.

(1) *Two-dimensional (drape) forming.* Perform the heating procedures outlined in *b* above. Wearing soft, white cotton gloves, remove the hot acrylic plastic from the oven, laying it carefully over the form. The edges of the acrylic plastic should be held against the form, either by hand or by holddown ring or yokes, until the sheet has thoroughly cooled. Cooling may require 10 minutes to 1/2 hour depending upon room temperature and the thickness of the sheet. Do not force cooling.

(2) *Three-dimensional forming.* Parts with compound curves may be formed from transparent acrylic plastic sheets by either of six different methods or, occasionally, by some combination of these methods. Heating procedures for this type of forming are outlined in *b* above.

(a) *Stretch forming.* Stretch forming may be done either manually or mechanically. Many compound shapes can be formed by stretching the heated acrylic plastic sheet across a form.

(b) *Male and female forming.* Male and female forming may be used for compound shapes of irregular contour, such as those with reeding, fluting, steps, and the like.

(c) *Air pressure differential without form (vacuum forming).* Air pressure differential without form is the method most commonly used for aircraft canopies. The use of air pressure differentials eliminates the objections to other methods of forming parts with compound curves.

Table 72. Practical Oven Temperatures

Thickness of sheet (in.)	0.125	0.250	0.500	0.125	0.250	0.500
Type of forming	Regular acrylic plastic, Military Specification MIL-P-6886.			Heat-resistant acrylic plastic, Military Specification MIL-P-5425, and craze resistant acrylic plastic, Military Specification MIL-P-8184		
Two-dimensional (drape)	113° C. 235° F.	110° C. 230° F.	107° C. 225° F.	135° C. 275° F.	135° C. 275° F.	135° C. 275° F.
Air pressure differential without form (vacuum forming).	140° C. 284° F.	135° C. 275° F.	130° C. 266° F.	150° C. 302° F.	145° C. 293° F.	145° C. 293° F.
Stretch forming (dry mold cover).	140° C. 284° F.	135° C. 275° F.	130° C. 266° F.	160° C. 320° F.	150° C. 302° F.	150° C. 302° F.
Air pressure differential with male form.	140° C. 284° F.	140° C. 284° F.	135° C. 275° F.	170° C. 338° F.	160° C. 320° F.	160° C. 320° F.
Stretch forming (with male form and grease).	160° C. 320° F.	150° C. 302° F.	140° C. 284° F.	180° C. 356° F.	180° C. 356° F.	170° C. 338° F.
Male and female forming	140° C. 284° F.	135° C. 275° F.	130° C. 266° F.	180° C. 356° F.	170° C. 338° F.	170° C. 338° F.
Air pressure differential with female form.	145° C. 293° F.	140° C. 284° F.	135° C. 275° F.	180° C. 356° F.	170° C. 338° F.	170° C. 338° F.

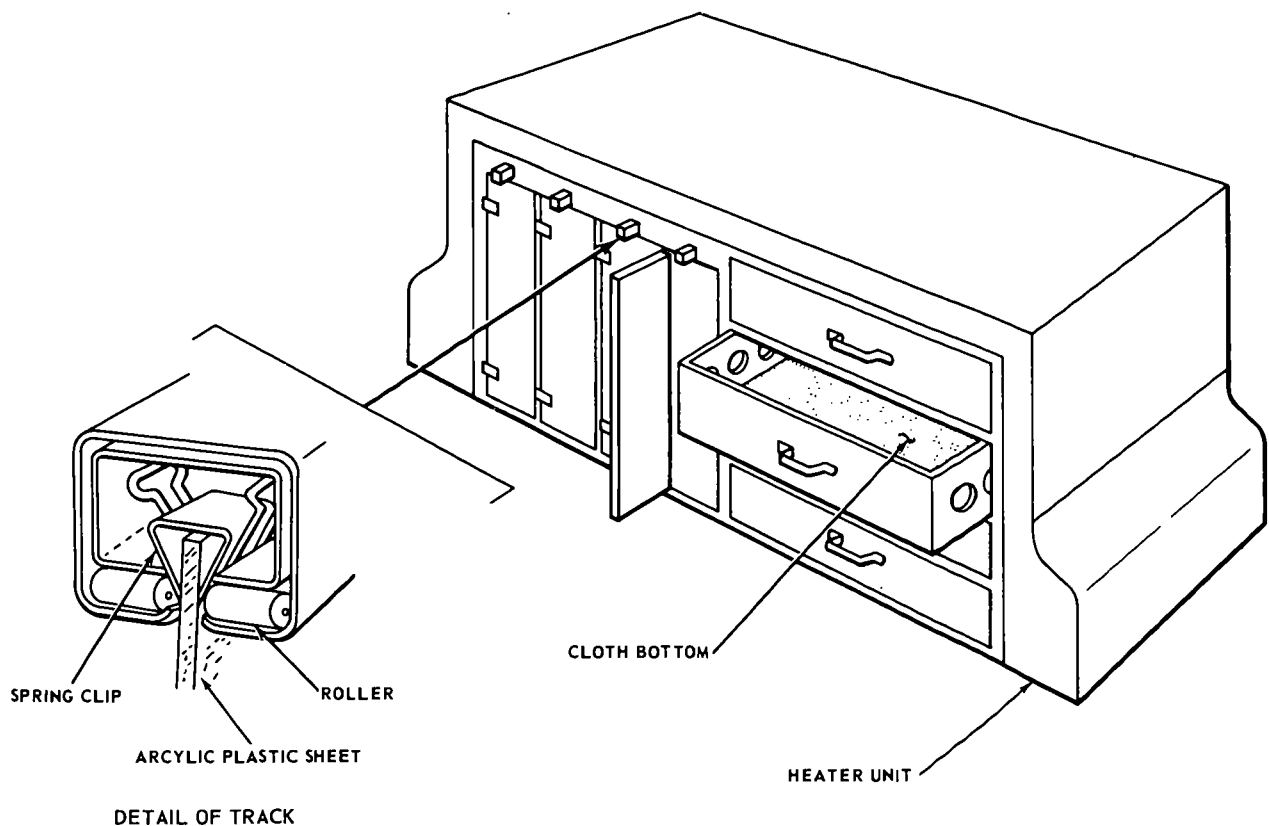


Figure 341. Layout of a forming oven.

(d) *Air pressure differential with female form.* Air pressure differential with female form is used when the desired part varies quite radically from a true surface tension shape by having sharp changes of contour. The part is formed by drawing it onto a female form made of plaster or metal.

(e) *Air pressure differential with male form.* Air pressure differential with male form is another method of obtaining shapes which vary from the true surface tension shape. It is based on the tendency of the heated acrylic plastic to return to its original flat sheet form, a tendency known as elastic memory.

(f) *Rotoforming.* Rotoforming is a term applied to a method of forming transparent acrylic plastic canopies with centrifugal force.

224. Fabricating Processes and Techniques

a. General.

(1) The fabrication of transparent acrylic plastics may be compared generally to that of wood or of soft metal. Good craftsmanship, suitable equipment, and proper design are no less essential to the successful fabrication of transparent acrylic plastics than to that of other

materials worked by similar methods. Light to medium woodworking equipment with minor modifications is satisfactory, but heavy duty machines which are less apt to vibrate are better.

(2) General rules for machining apply. Tools should be kept sharp. Unlike metals, transparent acrylic plastics are poor conductors of heat. Therefore, it is essential that ample means be provided to dissipate frictional heat, either by the use of a coolant or, in some cases, an air blast. A water soluble cutting oil is the recommended coolant. Other coolants may contain chemicals harmful to the plastic.

b. Layout.

(1) Laying out the work may be accomplished, where extreme accuracy is not required, by penciling the cutting lines directly on the masking paper. For close tolerances, however, it is advisable to scribe layout lines directly on the surface of the acrylic plastic. Use straightedges or layout templates according to the requirements of the job. If the masking paper is removed before scribing, it should be replaced again to within about 1/4 inch of the scribed markings before the piece is cut.

(2) Layout templates may be of plastic

sheeting to which suitable handles can be cemented. Sharp edges or rough spots in such templates should be carefully rounded or smoothed. In the case of metal templates, it is good practice to cement thin flannel over the contact surface.

c. Sawing. Several types of saws are suitable for sawing transparent plastics. These include circular, band, jig, and veneer saws.

(1) *Circular saws.* Circular saws for cutting acrylic plastic should be hollow ground or have set or swaged teeth to prevent binding. To obtain a smooth edge, the teeth should be side dressed on the machine after setting and sharpening. The acrylic plastic should be fed slowly enough to prevent overheating. The feeding should not be forced, but will vary with the thickness of the acrylic plastic being cut, the type of blade used, and the speed and sharpness of the blade. Moderate smoking and smearing at the cut is an indication that feeding is too rapid. A good practice for obtaining smooth edges at the exit end of a cut is to slow down the rate of feeding as the saw blade leaves the cut. Table 73 indicates the type of saw blade appropriate for use with various thicknesses of acrylic plastic sheets.

Table 73. Type of Circular Saw Blade Versus Thickness of Acrylic Plastic Sheet

Thickness to be cut (in.)	Blade thickness (in.)	Teeth per inch	Type blade
0.040-0.080	$\frac{1}{16}$ - $\frac{3}{32}$	8-14	Hollow ground
0.100-0.150	$\frac{3}{32}$ - $\frac{1}{8}$	6-8	Hollow ground
0.187-0.375	$\frac{3}{32}$ - $\frac{1}{8}$	5-6	Spring set
0.438-0.750	$\frac{1}{8}$	3-4	Spring set or swaged
1.000-4.000	$\frac{1}{8}$ - $\frac{5}{32}$	3-4	Spring set, swaged, or cemented carbide

(2) *Band saws.* Band saws should be used where flat sheets are to be cut in curves, or where formed parts are to be rough trimmed. Metal cutting blades have been found best for cutting acrylic plastics. Table 74 indicates the width of saw appropriate for various radii.

(3) *Jigsaws.* Jigsaws may be used for cutting thin sheets of acrylic plastic. They do not cut satisfactorily through thick pieces. If it is necessary to use a jigsaw, the feeding must be light and the teeth cleaned often.

(4) *Veneer saws.* Veneer saws are small, circular saws. As portable tools, they are used mostly to trim the large, formed acrylic plastic parts which are held in a trip jig or fixture.

d. Routing. For high-speed portable routers, standard two-blade woodcutters give satisfactory

Table 74. Width of Saw for Various Radii of Cut

Width of saw (in.)	Points to inch	Thickness		Minimum radius to be cut (in.)
		Inch	Gage	
$\frac{3}{16}$	7	0.028	22	$\frac{1}{2}$
$\frac{1}{4}$	7	0.028	22	$\frac{3}{4}$
$\frac{3}{8}$	6	0.028	22	$1\frac{1}{2}$
$\frac{1}{2}$	5	0.032	21	$2\frac{1}{4}$
$\frac{5}{8}$	5	0.032	21	3
$\frac{3}{4}$	4	0.032	21	$4\frac{1}{2}$
1	4	0.035	20	8
$1\frac{1}{4}$	3	0.035	20	12
$1\frac{1}{2}$	3	0.035	20	20

results. On vertical spindle shapers, multiblade cutters of two, three, or even more blades may be used. In general, the greater the speed the less the number of cutting edges required. Cutters up to 3 inches in diameter may be used without difficulty.

(1) Keep cutters sharp. Always grind cutters with a back clearance angle of about 10 degrees. For best results, grind a 20° to 30° rake angle (fig. 342).

(2) For rabbet or stepped routs (fig. 343), hack off underside of teeth of cutter in order to prevent drag and thus avoid burning the acrylic plastic. When possible, grind corners of routing cutter to a 1/16-inch radius so as to produce a fillet at bottom of rout. When router spindle collar bears on edge of acrylic plastic during routing procedures, use a ball bearing collar (or oil the collar or edge) to reduce friction and excess heating. It may be impossible to hold close tol-

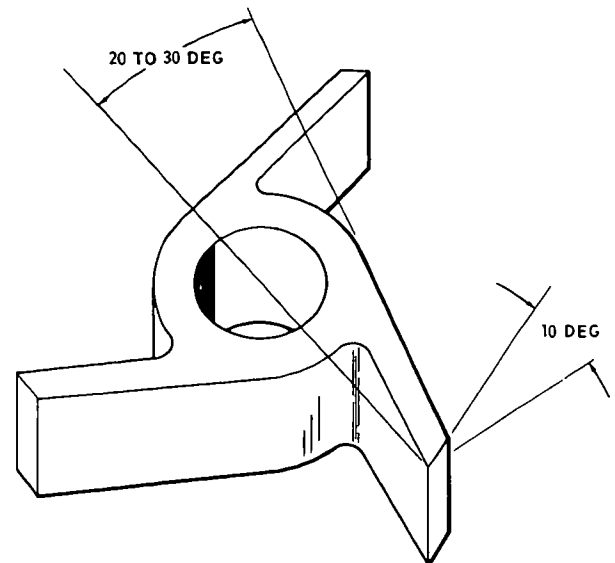


Figure 342. Typical router cutter.

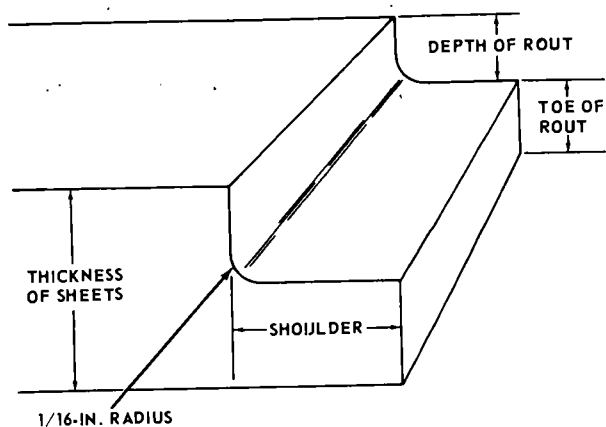


Figure 343. Step rout or rabbet.

erances in both the depth of the cut and the toe of the rout unless a subsequent compensating machine routing is carried out after routing.

(3) Use cutters ground to the desired shape when routing special cross sections. Rib shapes, for example, can be made by routing strips in much the same way as wood molding is produced.

e. Scribing and Edge Sanding. This method of fabrication is most generally employed on flat sections or two-dimensional curved pieces. The sheet is first cut to approximate shape on a band saw, using a scribed line as a guide, and cutting approximately 1/16 inch oversize. After the sheet has been cut, it is then sanded to the correct size. Use drum or belt sanders for curved edges. Use disc sanders when removing material from straightedges and outside curves. When sanding irregular shapes or large pieces which are awkward to manipulate around a fixed machine, use an air-driven sander or a small electric hand sander.

f. Drilling. For the sake of both accuracy and safety, hold the piece of acrylic plastic to be drilled using a suitably designed clamp or fixture. Use drills with slow-spiral polished flutes (fig. 344). Flutes should be as wide as possible. The best lubricant and coolant for drilling plastics is a water soluble cutting oil. For drilling shallow or medium depth holes, no coolant is needed. For deep holes, of course, a coolant is needed. The twist drills commonly used for soft metals may be used successfully for acrylic plastics if ordinary care is observed. However, the best results can be obtained if the drills are repointed with the following in mind.

(1) The drill should be carefully ground free of nicks and burs which would affect the surface finish.

(2) It is particularly important that the cutting edge be dubbed off to zero rake angle (fig. 344).

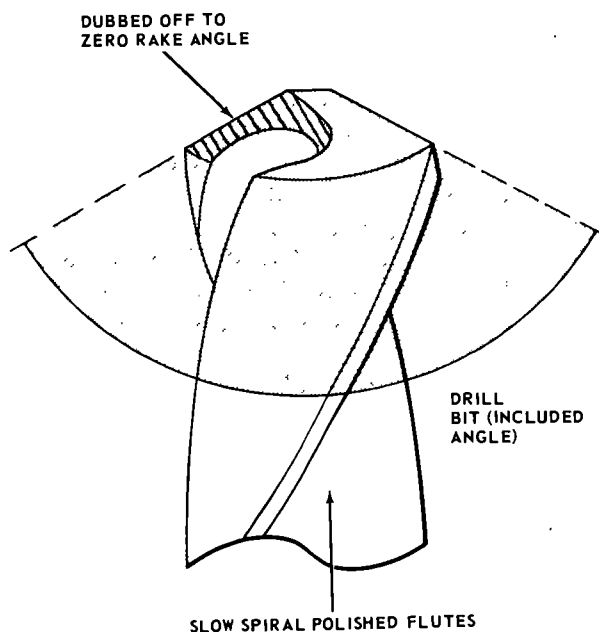


Figure 344. Drill for acrylic plastics.

(3) The length of the cutting edge (and hence the width of the chip) may be reduced by increasing the included angle of the drill (fig. 344).

225. Cementing Procedures

With care and proper procedures, it is possible to obtain a cemented joint which approximates the original acrylic plastic strength. The type of acrylic plastic being cemented determines the type of adhesive to be used. Acrylic monomer base adhesive, Military Specification MIL-A-8576B Type I is used when cementing regular acrylic plastic, Military Specification MIL-P-6886, and heat-resistant acrylic plastic, Military Specification MIL-P-5425. Acrylic monomer base adhesive, Military Specification MIL-A-8576B Type II, is used when cementing craze resistant acrylic plastic, Military Specification MIL-P-8184.

a. Methods of Cementing. There are three different methods used in cementing of acrylic plastics—soak method, glue method, and direct application method. The type of adhesive to be used in cementing helps in determining the method which will be used. When using acrylic monomer base adhesive, Military Specification MIL-A-8576B Type I, the soak or glue method will be used. When using acrylic monomer base adhesive, Military Specification MIL-A-8576B Type II, the direct application method will be used.

(1) *Soak method.* The most common method of cementing regular acrylic plastic, Mili-

tary Specification MIL-P-6886, and heat resistant acrylic plastic, Military Specification MIL-P-5425, is the soak method. This consists of placing one of the two pieces to be cemented into a soak tray filled with acrylic monomer base adhesive, Military Specification MIL-A-8576B Type I, until a sufficient cushion is formed. Although no arbitrary soaking time can be set, regular acrylic plastic soaked an average of about 10 minutes will form a cushion deep enough to take care of any discrepancies in the fitting of the two parts. In cementing heat-resistant acrylic plastic, a slightly longer time may be required. Immediately after soaking time has elapsed, the piece which was soaked in the adhesive is pressed against the opposite dry surface. The excess cement forms a second cushion, shallow, but enough to permit thorough intermingling of the two surfaces as shown in figure 345.

(2) *Glue method.* The glue method is also used for cementing regular acrylic plastic, Military Specification MIL-P-6886, and heat-resistant acrylic plastic, Military Specification MIL-P-5425. When performing this type repair, clear transparent acrylic plastic shavings of the same type as the transparent acrylic plastic being cemented are dissolved in acrylic monomer base adhesive, Military Specification MIL-A-8576B Type II, to give it a thick, syrupy consistency so that it can be applied like glue. This viscous cement, however, works on exactly the

same principle as a soak cement; *for example*, the excess adhesive softens and swells both surfaces, permitting an intermingling of the cushions and the formation of a cohesive bond as shown in figure 346.

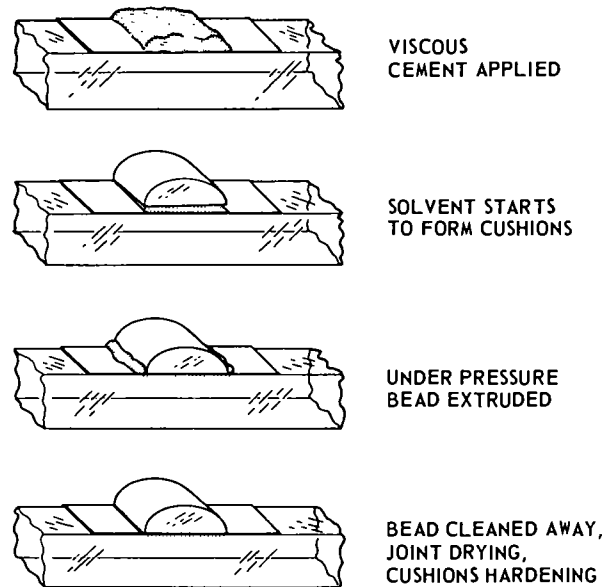


Figure 346. Glue method of cementing.

(3) *Direct application method.* When cementing craze resistant acrylic plastic, Military Specification MIL-P-8184, the direct application method will be used. When using this method, apply acrylic monomer base adhesive, Military Specification MIL-A-8576B Type II, to either one or both surfaces and assemble immediately. The parts should be held together in a jig while the cement cures. This method of cementing does not form a cushion as does the two methods previously discussed. The joint may be handled after being subjected to a temperature of 70°F. (21°C.), or higher, for 4 hours, but should be allowed to harden for 25 hours at room temperature or 4 hours at 150°F. (66°C.) before further machining or forming.

Warning: Acrylic monomer and polymer base adhesive, Military Specification MIL-A-8576B Type II, contains a volatile liquid which may prove toxic if the vapor is inhaled for extreme periods. Use only with adequate ventilation. If accidentally spilled on the hands or skin remove immediately by dissolving with solvent (ethyl or isopropyl alcohol) followed by washing with soap and water. Overexposure symptoms are drowsiness, dizziness, and nausea. Treat by wrapping patient in blankets, providing plenty of fresh air, and obtaining medical assistance.

Caution: Acrylic monomer and polymer base adhesive, Military Specification MIL-A-8576B

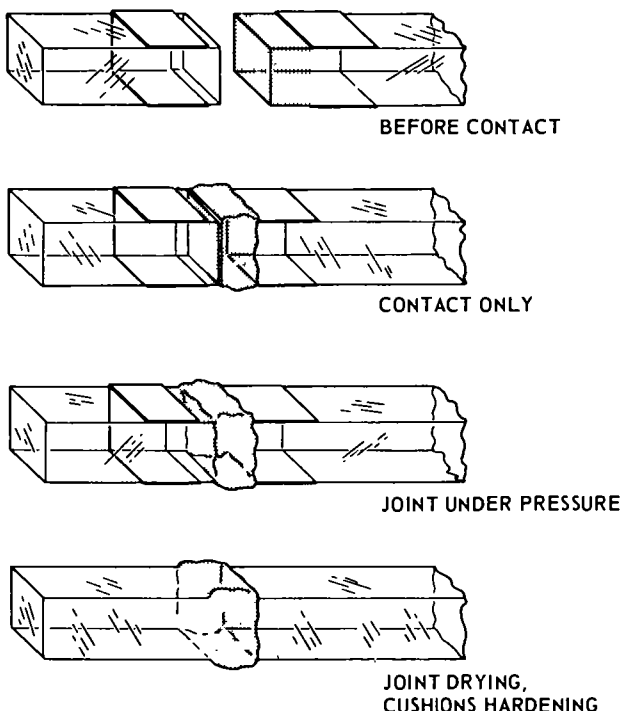


Figure 345. Soak method of cementing.

Type II, should be kept out of sunlight and away from sources of heat which will accelerate the curing rate of the adhesive. Do not dispose of the adhesive container until the adhesive has set and the container is cool. Mix the catalyst and promoter with adhesive in accordance with the adhesive manufacturer's instruction sheet.

b. *Fitting.* For a satisfactory joint, the two pieces to be cemented should fit accurately. It is always preferable to cement flat surfaces rather than curved. It is, therefore, advisable to rout or sand curved sections to present flat surfaces before cementing. Where two curved surfaces must be cemented, as in an overlap joint of two curved sections, the curves of both should have the same radius. All cemented joints should be firmly bonded over at least 90 percent of the joint surfaces within any joint. The remaining 10 percent may have bubbles and/or dry spots, unless otherwise noted on applicable drawings. The two surfaces should have a fairly smooth finish. It is not necessary that they be polished, but the surfaces should be at least sanded smooth.

c. *Masking.* To confine the softening action of the adhesive to the area of the joint, it is necessary to mask the surrounding acrylic plastic. For this purpose, use a pressure-sensitive tape, impervious to the action of the adhesive. It is important that the tape be well applied, particularly at the edge, and that enough overlap (approximately 1/4 inch) be allowed so that the adhesive does not seep under the edge and attack the acrylic plastic to be protected. Be sure that the edges are firmly attached and that there are no air bubbles beneath the tape. Since the application of successive strips of tape is often time consuming, it is sometimes preferable to mask a complicated or curved part by coating it with a plasticized gelatin solution.

d. *Soaking.* The function of the cushion formed by acrylic monomer base adhesive, Military Specification MIL-A-8576B Type II, when cementing regular acrylic plastic, Military Specification MIL-P-6886, or heat resistant acrylic plastic, Military Specification MIL-P-5425, is only to permit intermingling of the two surfaces to be bonded. The adhesive on the cushion surface, not the cushion itself, is the bonding agent. The cushion should only be large enough to assure intimate contact (fig. 347).

e. *Assembling.* The interval between the soak for regular acrylic plastic, Military Specification MIL-P-6886, or heat-resistant acrylic plastic, Military Specification MIL-P-5425, and the direct application for craze resistant acrylic plastic, Military Specification MIL-P-8184, and the assembly of the joint is perhaps the most critical

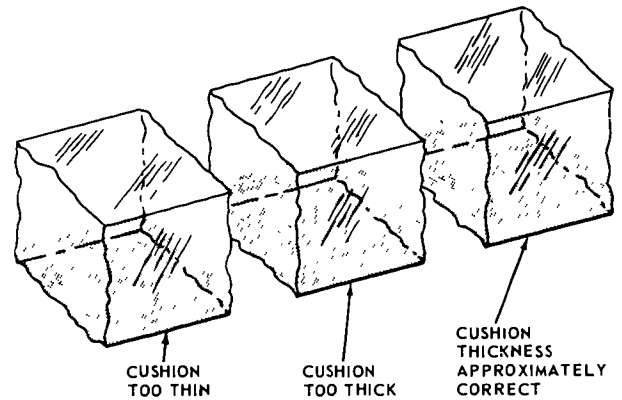


Figure 347. Proper cushion thickness.

of the entire cementing operation. Since these liquid adhesives evaporate quickly, it is necessary that the joint be assembled as quickly as possible. If the cushion is allowed to dry, or if the joint is wiped free of the adhesive before the joint is closed, the joint may break open or it may lack the required strength when the pressure is removed. The soak tank used in cementing regular acrylic plastic and heat-resistant acrylic plastic should be near the cementing operation. Jigs should be arranged so that the operator can assemble the two pieces accurately with a minimum of elapsed time.

(1) It is important to allow a slight interval between the time the two pieces are placed in contact and the time pressure is applied. Ordinarily, 15 to 30 seconds is a sufficient interval.

(2) In many cases, the success of a cementing job depends on the design of the jig holding the two pieces in place until the joint is set. The jig should keep the two pieces firmly together, but should not force either of them out of shape. Figure 348 shows a few jigs which might be used for holding the cemented parts in place until the joint hardens.

(3) The pressure should, first, be great enough to squeeze all air bubbles from the joint and assure thorough intermingling of the cushions; second, it should be applied evenly all along the joint to avoid stress concentrations at any point; and third, it should be maintained to compensate for the shrinkage that takes place in the joint during setting or hardening. Since the swelling action of the adhesive in forming a cushion causes an increase in volume, the cushion will shrink as the adhesive evaporates. Excessive pressure should be avoided in order to prevent localized stress concentrations which cause crazing.

(4) When placing the assembly in a jig, and

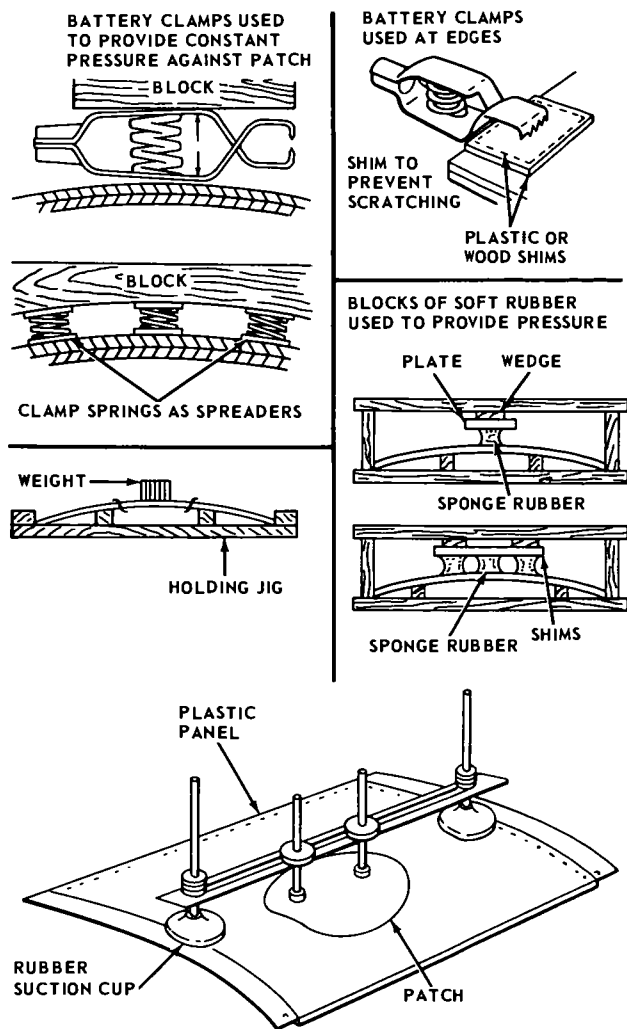


Figure 348. Jigs for holding cemented assemblies.

at intervals thereafter, it is advisable to examine the joint carefully. If slipping is noted before the joint has set, the pressure can still be re-adjusted or the job taken apart for reassembly. After the assembly has been locked in its jig, any excess adhesive and cushion which has extruded from the joint should be removed by scraping the excess onto the masking and then removing the tape.

(5) If the assembly is constructed of regular acrylic plastic, Military Specification MIL-P-6886, or heat resistant acrylic plastic, Military Specification MIL-P-5425, the assembly should be allowed to remain in its jig at least 4 hours; and an additional 4 hours should elapse before the assembly is subjected to handling or heat treatment. If the assembly is constructed of craze resistant acrylic plastic, Military Specification MIL-P-8184, the assembly should be allowed to remain in its jig for 4 hours at a

temperature of 70°F. (21°C.) or higher; and an additional 25 hours at room temperature or 4 hours at 150°F. (66°C.) should elapse before further machining or forming.

Note. Since adhesive vapor, as well as the adhesive itself, can cause crazing, assemblies with inclosed spaces should be ventilated adequately.

226. Curing and Heat Treatment

After regular acrylic plastic, Military Specification MIL-P-6886, or heat-resistant acrylic plastic, Military Specification MIL-P-5425, are assembled, they should be cured and heat-treated. A solvent joint never dries completely; that is, it will never become entirely free of the solvent. If the temperature is raised, the cushion will enlarge slowly until a new equilibrium is reached, as shown in figure 349. Upon cooling, the cushion will be larger and correspondingly harder, as it contains less solvent per unit of volume. Heating a solvent joint long enough to expand its cushion, therefore, will produce a much stronger joint.

a. Heattreating of cemented joints must be undertaken with caution. Heat first activates the adhesive, which softens the cushion. The cushion then slowly expands as the adhesive penetrates the material. In heattreating, it is important that the temperature does not approach the softening point of transparent acrylic plastics.

b. For regular acrylic plastic, Military Specification MIL-P-6886, a suitable temperature

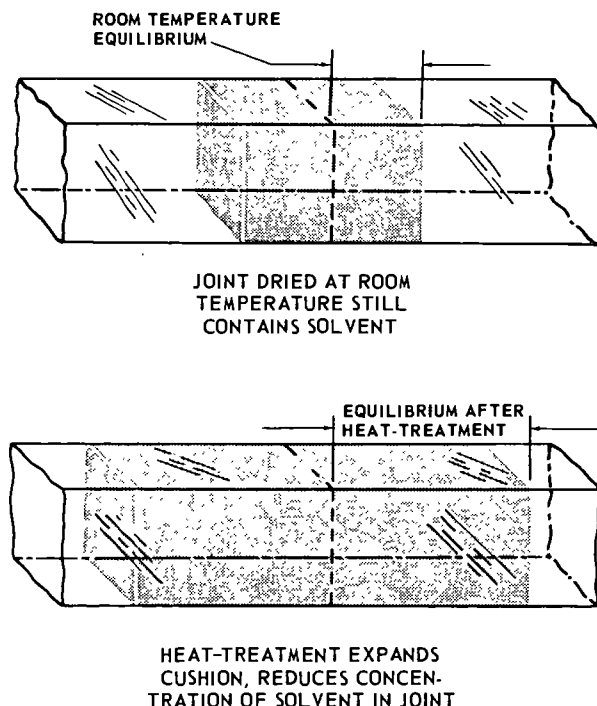


Figure 349. Effect of heat treatment.

would consist of 48 hours at 122°F. (50°C.); for heat-resistant acrylic plastic, Military Specification MIL-P-5425, a suitable temperature would consist of 48 hours at 150°F. (66°C.). Should these temperatures cause undue dimensional changes in intricate assemblies, it may be desirable to reduce the heat-treating temperature to 91°F. (33°C.) and increase the length of time of heat treatment to 72 hours.

c. It is important that the joint be thoroughly hardened before machining, sanding, or polishing to remove the bead.

227. Types of Repair and Procedures

a. *Emergency Repairs.* The following repairs are intended only for emergency use, and the damaged section should be replaced as soon as possible.

(1) *Lacing.* A lacing method in repairing transparent acrylic plastics is frequently employed to relieve the strain which might tend to increase the damage. A series of holes at intervals of 1 inch are drilled along each side of the crack at a margin depth of at least 1/2 inch (fig. 350). The holes on opposite sides of the injury may be staggered and laced diagonally, or they may be drilled directly opposite each other and the repair laced in the same manner as a boot or shoe. The latter method provides a snug, easily tightened repair and is most generally preferred. Strong flexible wire, such as copper or brass lock wire, is used for lacing repairs. It must be kept in mind that any such repair is but temporary and intended only until better repair can be performed.

(2) *Machine screw repair.* Select machine screws long enough to extend through the acrylic plastic and accommodate two flat washers and a nut. Using a drill the same diameter as the machine screw, drill a hole at the end of the cracks (fig. 351). Drill a series of holes at in-

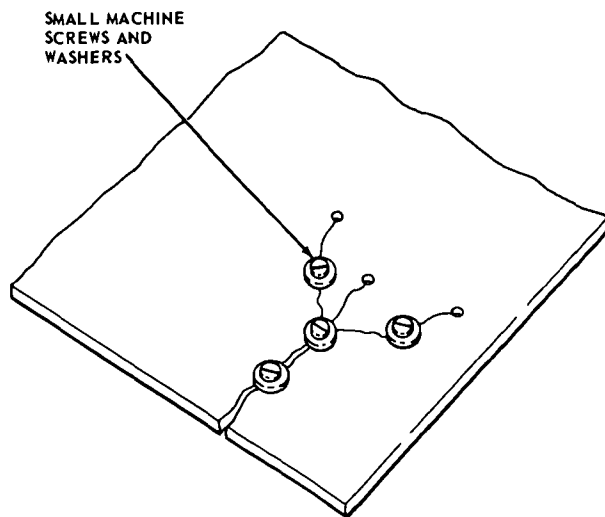


Figure 351. Machine screw repair.

tervals of approximately 1 inch through the cracks. Place a flat washer on the head of each machine screw and install the screw in the holes. A machine screw is not required in the holes that were drilled at the end of the cracks. Install a washer and nut on each machine screw and tighten securely.

(3) *Machine screw patch.* Select a piece of acrylic plastic of the same type and thickness as the piece to be repaired. Cut the selected piece of acrylic plastic approximately 2 inches larger than the damaged area and bevel the edges (fig. 352). Select machine screws long enough to extend through the patch and the damaged piece of acrylic plastic, and to accommodate two flat washers and a nut. Using a drill the same diameter as the machine screws, drill a hole at the end of the cracks. Center fabri-

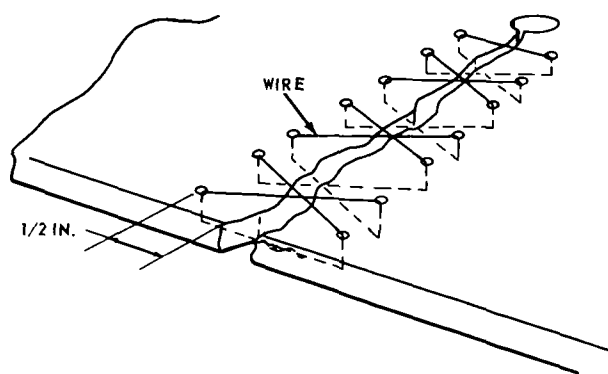


Figure 350. Lacing.

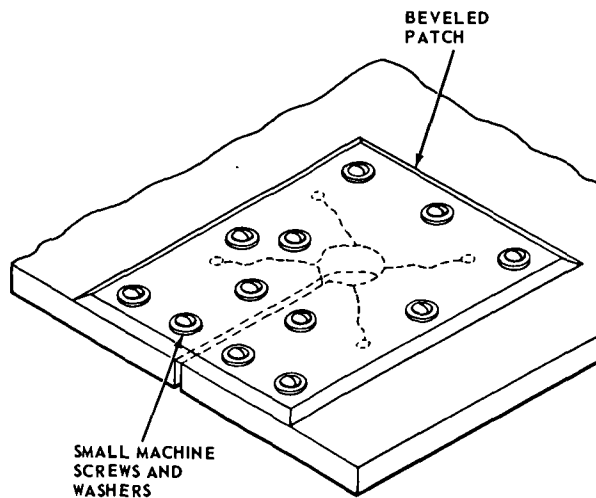


Figure 352. Machine screw patch.

cated patch over damaged area. Secure patch in place with a clamp or jig. Drill a sufficient number of holes through patch and damaged piece of acrylic plastic so that all fragments of the crack will be properly reinforced as illustrated in figure 353. Place a flat washer on the head of each machine screw and install the screws in the holes. Install a washer and nut on each machine screw and tighten securely.

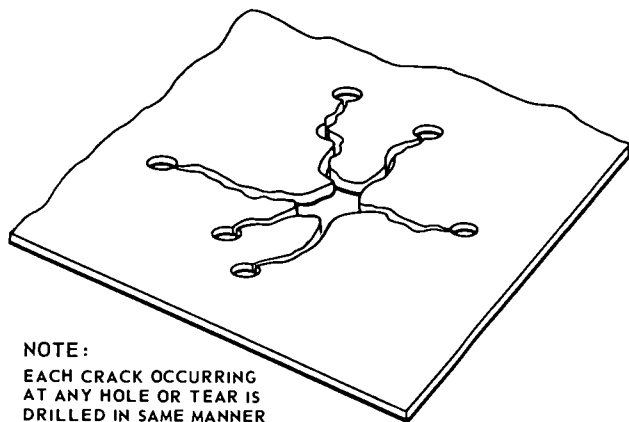


Figure 353. Stop-drilling.

b. Permanent Repairs. The following types of repair are considered to be permanent repairs.

(1) *Stop-drilling.* To stop-drill a crack, select a drill a few thousandths under the 1/8-inch size. Drill a hole at the end of each crack (fig. 353). This will distribute the strain over a larger area and restrain the crack. It has been found through experience that repair by stop-drilling small cracks may be improved upon by the following procedure.

(a) Fill crack with applicable type adhesive used with the acrylic plastic being repaired, using an ordinary hypodermic needle. Capillary action will draw the adhesive into the crack.

(b) Soak the end of a 1/8-inch plastic rod of the same type acrylic plastic in the adhesive for about 1 minute, and then stick the rod in the drilled hole. Allow to dry for 30 minutes and carefully cut off the rod close to the piece of acrylic plastic, using a pair of diagonal pliers.

(2) *Transparent plastic plug repair.* The shape of the plastic plug is governed by the contour and area of damage to be repaired. Plug repair to cracks over 8 inches in length will be repaired by multiple plug patches. Accomplish plug patching that will result in hairline-type outlines of the patch, so far as possible. Instructions to accomplish plastic plug repair are as follows:

(a) Clean around area to be repaired by washing with mild soap and cold water, using a clean, soft, grit-free cloth, sponge, or bare hands. The surface of craze resistant acrylic plastic, Military Specification MIL-P-8184, to be cemented must be sanded or otherwise roughed before application of adhesive. For best results, use 240-400 grit sandpaper.

(b) Fabricate a hand router template from 0.250-inch thick transparent plastic sheet for milling the plug cavity. Make cutout in router template as large as desired repair plug, plus an edge margin equal to distance from cutter edge to milling cutter shoulder. The cutout should never be closer than 1.5 inches to edge of the template. Sand cutout edges smooth for guiding the milling cutter shoulder (fig. 354).

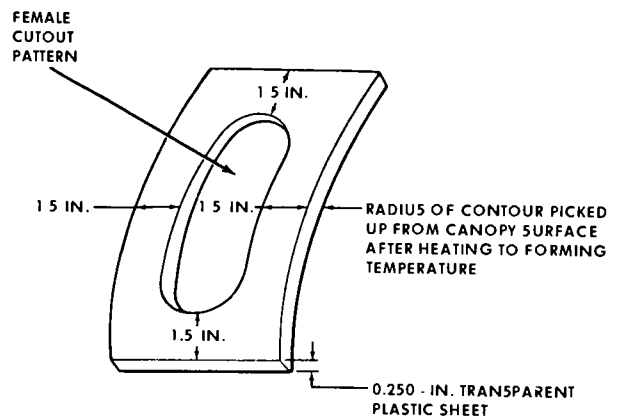


Figure 354. Hand router template for milling plug cavity.

(c) Position template over desired plug area and hold in place with pressure-sensitive adhesive tape, Federal Specification UU-T-106, or equivalent.

(d) Millout, by step-cuts of approximately 0.015 to 0.025 inch per cut, damaged portion of transparent acrylic plastic assembly. Use an electric hand router and a shop-made milling cutter with a 2° to 3° draft angle and a minimum corner radius of 0.1 inch. Do not exceed maximum depth of within 0.015 inch of butyral on laminated acrylic plastic inclosures. Do not attempt to go deeper than maximum depth, even when remains of damage are visible in remaining 0.015-inch acrylic plastic.

(e) Remove template and anneal transparent acrylic plastic inclosure, as outlined in paragraph 228e, to remove machine stresses. A plug patch should be installed within 1 1/2 hours after acrylic plastic has cooled slowly to a temperature of 70° to 90°F. (21° to 32°C.).

(f) Make a pattern for plastic plug patch

by placing a sheet of paper over plug cavity and shading edges with a pencil.

(g) Cut plug from sheet of next greater thickness and of same type of acrylic plastic from which damaged portion is made, with a side angle and corner radius to match plug cavity. Heat plug as prescribed in paragraph 228e (1), and press into cavity, holding firmly until cool. Plug may be held in place by blocks cut to contour of transparent acrylic plastic assembly surface. Remove plug from cavity and hand-fit by scraping and sanding before cementing into position.

(h) Mask a 2-inch area around plug cavity with pressure-sensitive tape, Federal Specification L-T-90, or clear cellophane tape. Trim tape flush with edge of plug cavity. Apply tape in a band 1 or 2 inches wide, as closely as possible to limits of joint $1/16$ inch for solvent bonding). Make certain all air bubbles between tape and acrylic plastic surface are eliminated. If these are permitted to remain, they will allow bonding adhesive to seep beyond joint area.

(i) When repairing regular acrylic plastic, Military Specification MIL-P-6886, or heat resistant acrylic plastic, Military Specification MIL-P-5425, place plug in a soak tray made of material that will not be attacked by action of adhesive. Place wire rods in soak tray on which plug or part to be cemented may rest; this will permit adhesive to contact all edges to be cemented. Pour acrylic monomer base adhesive, Military Specification MIL-C-8576B Type I, into tray until level with top of plastic plug. Do not soak top of plug patch; masking of this surface will be added protection from adhesive contacts. Leave plastic plug immersed in adhesive until surfaces to be bonded soften into a deep cushion. Accurate soaking time should be worked out for each bonding operation. Temperature should be 80° to 90°F . (27° to 32°C .) and humidity relatively low. Do not attempt to bond acrylic transparent assembly below 65°F . (18°C .).

Note. Acrylic monomer and polymer base adhesive, Military Specification MIL-A-25055, shall be used to join pieces of craze resistant acrylic plastic. Military Specification MIL-P-8184. The adhesive will be applied directly to either one or both surfaces assembled immediately.

(j) Immediately press plastic plug into cavity and wipe along its length, applying about 5 psi pressure to remove trapped air. Do not press hard enough to produce starving or dispersion of adhesive. A hypodermic needle may be used to inject adhesive into bond area to force out trapped air bubbles. Ten percent of plug area may contain air bubbles; however, it is not desired. The plug can be held in place by means

of contour blocks and shock cord. Contour blocks may be removed in 24 hours. Allow approximately 72 hours before finishing plug surface.

(k) Complete plug repair by sanding down excess of plug extending above transparent acrylic plastic assembly surface. Finish surface by sanding, buffing, polishing, and annealing as outlined in paragraph 228.

(3) *Alternate transparent plastic plug repair.* This type of repair is permissible up to $5/32$ inch in depth with the total area not to exceed 1 square inch within a circle of 3-inch diameter. This type of repair should not be construed to be a structural repair, but is strictly for vision improvement.

Caution: This procedure may not be used in critical vision areas.

(a) Routing of gouges, nicks, and scratches should be accomplished by a tool having a radius not less than $1/2$ inch.

(b) To alleviate resulting distortion of vision (cavity), methyl-methacrylic monomer may be used as a filler. Area around the cavity (fig. 355) should be masked off approximately $1/16$ inch from the edge with zinc chromate putty, Military Specification MIL-P-8116, to form a pool with its surface approximately $1/4$ inch above adjacent surface of parent material.

Note. When mixing the casting resin, care should be exercised to prevent whipping air into the resin. The mixture should be placed in a dark area for at least 2 hours to allow entrapped air to rise to surface of the container. It is mandatory that air that has risen to the surface be scraped off to prevent bubbles and obvious optical defects in the casting.

(c) After the resin has been poured into the cavity to form a pool, the area should be exposed to natural sunlight or an ultraviolet lamp for 4 to 5 hours to allow proper curing.

(d) Remove the zinc chromate putty. Using a power tool or file, grind the raised portion of the casting to blend roughly with original contour. Finish surface by sanding, buffing, polishing, and annealing as outlined in paragraph 228.

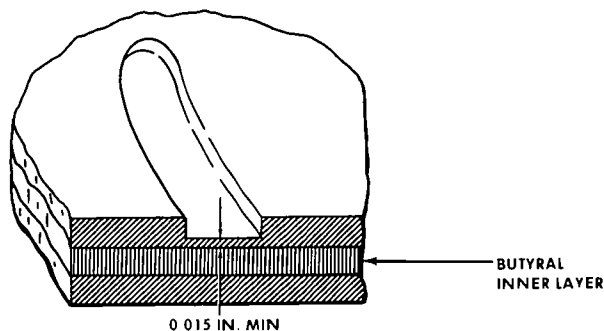


Figure 355. Cavity plug repair.

(4) *Transparent plastic overlay patch.* The type of transparent acrylic plastic material to use in accomplishing an overlay patch repair should be of the same type as that of the damaged transparent part. The repair (fig. 356) will be accomplished as follows:

(a) Clean around area to be repaired by washing with mild soap and cold water, using a clean, soft, grit-free cloth, sponge, or bare hands. All grease must be removed in order to insure a perfect bond. Do not touch cleaned surface with fingers.

(b) Select an acrylic transparent plastic sheet 0.187 to 0.250 inch thick and cut a patch from the sheet large enough to cover damaged area, plus an edge margin of 0.5 inch.

(c) Bevel edges of the overlay patch; sand and polish edges smooth.

(d) To obtain the desired contour when repairing damages on curved surfaces, remove protective masking paper and heat patch to temperature specified in table 72. Sufficient time should be allowed for patch to be heated throughout to forming temperature. Press patch firmly against repair surface and hold in place until patch is cool. White cotton gloves should be worn while handling the hot plastic.

(e) Mask transparent plastic surface for 2 inches around overlay patch area to provide protection from excess cement. Trim inside boundary of tape by placing overlay patch in position and cutting around its edge. Do not cut through the tape enough to scribe the transparent plastic. Mask outer surface of overlay patch.

(f) Clean the two surfaces with aliphatic naphtha, Federal Specification TT-N-95, type II, just prior to applying adhesive.

Warning: Observe all fire precautions when using aliphatic naphtha.

(g) Apply applicable adhesive to bond surface of patch and surface to receive patch.

(h) Press overlay patch into position and, with approximately 5 psi pressure, wipe from center to edges to remove as many air bubbles as possible. Ten percent of patch area may con-

tain air bubbles, but it is not desired. Do not press hard enough to cause a starved area. Wipe free of excess adhesive.

(i) Use pressure to hold patch firmly in place. Remove pressure after 24 hours, and let repair continue to cure for a total of 48 to 72 hours.

(j) Remove masking tape and smooth rough adhesive spots along edge of patch. Finish surface by sanding, buffing, polishing, and annealing as outlined in paragraph 228.

228. Finishing Procedures

a. *Sanding.* Because transparent acrylic plastic is relatively soft in comparison to glass and because it softens under the influence of heat, any sanding which is done to remove a surface blemish may result in an ultimate finish of poorer optical quality than that of untouched sheets. Therefore, it is important that transparent acrylic plastics be handled carefully during fabrication and servicing to avoid unnecessary finishing operations. Sanding will not restore the original luster of the plastic.

(1) Under no circumstances should initial optical parts be sanded. These parts are to be washed with clean soap and water. Such parts having scratches or crazing in excess of that specified as permissible in the applicable terminal manual will be replaced.

(2) When sanding is required, the finest abrasive paper that will remove the scratch or other defect, no coarser than No. 320A, is used first. The abrasive paper is wrapped around a felt or felt-covered block and the defective area rubbed lightly, using water and a 2-percent solution of soap, Federal Specification P-S-616, as a lubricant. Light pressure should be used and the strokes should be circular.

(3) The initial sanding should be followed by similar treatments, using successively finer grades of abrasive paper grits. Wash the plastic after each sanding operation. During each step, the deeper scratches left by the preceding grade of abrasive should be removed.

(4) Transparent acrylic plastic should not be sanded unless it is absolutely necessary. Hair-line scratches of 0.001-inch maximum depth will be left as is, providing optical requirements are maintained.

(5) The same general procedures used in hand-sanding apply to sanding with power-driven sanding machines. Extremely light pressure should be used.

(6) Power sanders should not be used except where the severity of the defect requires excessive hand-sanding. Only flat surfaces, with

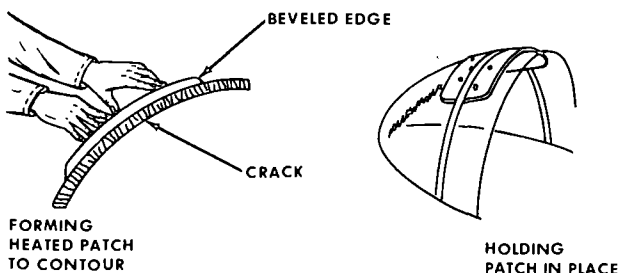


Figure 356. Overlay patch to reinforce a crack.

a radius of curvature greater than 36 inches, should be so treated.

b. Ashing. An alternate to sanding is ashing, which involves the use of a thick abrasive paste on a cloth wheel. In this operation, speed and pressure are critical factors. It is essential that both be held within limits to prevent overheating of the work. As a further precaution against overheating, the plastic and wheel should be kept in constant motion with relation to each other.

c. Buffing. In order to remove the scratches caused by sanding or ashing, the acrylic plastic must be machine-buffed. It is often possible to remove scratches by buffing alone. Deep buffing, resulting in localized heating of the plastic sheet, should be avoided. It is important that the surface of the plastic be carefully washed and allowed to dry thoroughly between successive finishing operations to prevent the transfer of coarse abrasive to buffing wheels.

Caution: Under no circumstances should critical optical parts be buffed. These parts are to be washed with clean soap and water. Such parts having scratches or crazing in excess of that specified as permissible in the applicable technical manual will be rejected.

(1) Remove any hardened tallow from buffing wheels or pads if they have been used before by running them against a metal edge, or replace them.

(2) Apply a stick of inedible tallow, Federal Specification C-T-91, to buffing wheel for a few seconds, then bring bar of buffing and polishing compound, Military Specification MIL-B-16909, in contact the edge of wheel for a few seconds.

(3) Apply edge of spinning wheel to plastic surface lightly. Keep it moving over the surface and put only light pressure on buffing wheel. Buff along and across all scratches.

(4) Wipe buffing compound from plastic surface.

d. Polishing. In emergencies, when buffing equipment is not available, cleaning and polishing compound, Military Specification MIL-C-18767, may be applied by hand, using a soft damp cloth, to remove light scratches and other minor imperfections. The area to be polished should be washed free of dirt and grit, then rubbed vigorously with the polish. Caution should be taken not to rub too long in one place. Rub with a free, circular motion over a fairly wide area.

e. Annealing. Annealing consists of prolonged heating at an elevated temperature followed by slow cooling. This results in a piece of greater dimensional stability and greater resistance to

crazing. In order to obtain these benefits, it is necessary that the annealing be done after all other fabrication and finishing procedures have been completed.

(1) Table 75 indicates the recommended heating time for annealing various thicknesses of transparent acrylic plastic sheets.

(2) The parts may be cooled by turning off the oven heat or by removing to a place where they will be subjected to room temperature in still air.

(3) After elevated temperature annealing, the part must be cooled at an even rate. The rate of cooling must be slower for thick sheets than for thin ones.

Table 75. Annealing Time for Transparent Acrylic Plastic

Thickness (in.)	Heating time * in hours for transparent plastics in a forced-circulation air oven maintained at the indicated temperature		
	Regular acrylic plastic, Military Specifi- cation MIL-P- 6886	Heat-resistant acrylic plastic, Military Specifi- cation MIL-P- 5425, and craze resistant acrylic plastic, Military Specification MIL-P-8184	
	140° F. 60° C.	176° F. 80° C.	165° F. 74° C.
0.060-0.150 inclusive	10	10	
0.187-0.375 inclusive	10½	10½	
0.500-0.750 inclusive	11	11	
0.875-1.13 inclusive	11½	11½	
1.25-1.500 inclusive	12	12	
Laminated—all thickness	11	.....	11

* Includes period of time required to bring part up to annealing temperature.

229. Maintenance Procedures

a. General. Vision is so vital in military aircraft that day-to-day maintenance of transparent crew inclosures is of the utmost importance. Proper maintenance methods should be carried out thoroughly when vision is impaired as a result of chemical or physical actions or defects, and every effort should be put forth to eliminate harmful action while servicing the aircraft.

(1) Excessive replacement of transparent acrylic plastic crew inclosures has been caused by severe crazing, apparently from exposure to harmful solvents, and improper maintenance handling. The crazing appears as a network of cracks running in all directions over the surface

of the plastic. Crazing may also occur within the plastic at or near cemented joints.

(2) The use of cleaning fluids or compounds which have not been approved is one of the most common causes of the difficulties. The crazing action of a solvent is often delayed; that is, crazing may not appear for several weeks after the exposure to solvent or fumes. Where little or no stress is involved, two exposures to the solvent or fumes may occur before crazing develops. It is not always possible to determine immediately, by simple trial, whether or not a particular cleaner will be injurious.

b. Cleaning. Always remove rings from fingers before cleaning transparent acrylic plastic to avoid scratching the surface. Cleaning procedures for transparent acrylic plastics are as follows:

(1) *Cleaning exterior surfaces.* The following procedures should be followed when cleaning exterior surfaces of transparent acrylic plastics.

Note. Transparent acrylic plastics should be cleaned in a cool, shady area.

(a) Flush plastic surface with plenty of water, using bare hands to feel and gently dislodge any dirt, sand, or mud.

(b) Wash with mild soap and water. Be sure water is free of harmful abrasives. A soft cloth, sponge, or chamois may be used in washing, but only to carry soapy water to plastic. Go over surface with bare hands to quickly detect and remove any remaining dirt before it scratches the plastic. Rinse with clear water.

(c) Dry with a clean, damp chamois, a soft clean cloth, or soft tissue. Do not continue rubbing transparent acrylic plastic after it is dry.

Caution: Do not rub the plastic with a dry cloth. This not only causes scratches, but may build up an electrostatic charge which attracts dust particles. If the surface becomes charged, patting or gently blotting with a damp, clean chamois will remove the charge as well as the dust.

(d) Clean transparent acrylic plastic using polish and cleaner, Military Specification MIL-C-18767, and a soft, clean cloth. If polish and cleaner are not available, rinse thoroughly with clear water (distilled water, if possible) in a shaded area.

Caution: Never use a coarse or rough cloth for cleaning. Cheesecloth is not an acceptable cloth.

(2) *Cleaning interior surfaces.* The following procedures should be followed when clean-

ing interior surfaces of transparent acrylic plastics.

(a) Dust acrylic plastic surface lightly with a soft, clean cloth saturated with clean water.

(b) Wipe carefully with a soft cloth or sponge. Keep cloth or sponge free from grit by rinsing it frequently with clean water. Do not use a dry cloth.

(c) Clean transparent acrylic plastic using polish and cleaner, Military Specification MIL-C-18767, and a soft, clean cloth.

c. Polishing. If, after removing dirt and grease, the acrylic plastic surface is found to be marred by scratches, they may be removed as outlined in paragraph 228d.

d. Waxing. If, after removing dirt and grease, no great amount of scratches are visible, the acrylic plastic should be waxed with an approved wax. The wax will fill in minor scratches and help prevent further scratching. Apply wax in a thin, even coat and bring to a high polish by rubbing with a soft, dry cloth.

e. Hot Climate Precautions. In hot weather, the transparent acrylic plastic inclosures of parked aircraft exposed to hot sun may absorb enough heat to soften and distort the plastic inclosure unless the following precautions are taken:

(1) *Thermal distortion.* Transparent acrylic plastic inclosures on aircraft parked in the sun may receive heat directly from three sources—

(a) Transparent acrylic plastic has a property of absorbing selectively the heat producing rays of the sun; thus, the plastic can become considerably hotter than the surrounding air inside or outside the aircraft.

(b) Air inside an unshaded and unventilated aircraft will transfer the heat radiated by the metal members in the aircraft to the plastic by convection.

(c) If the inclosure is covered with a cover which is in contact with the transparent surfaces, there is a great tendency for the acrylic plastic to craze and be scratched. This is due to the fact that the cover will absorb moisture and expel harmful vapors which will in turn craze or crack the canopy. Also, the possibility exists that dirt, grit, or sand may get under the cover and scratch the acrylic plastic. In addition, if the cover tends to absorb heat, the transparent acrylic plastic will be heated to a temperature in excess of what it would be without the cover, as there is no air circulation. Do not cover transparent acrylic plastic inclosures except for protection against windblown sand and grit or ground temperature above 120°F. (49°C.).

(2) *Preventing thermal distortion.* In or-

der to prevent heat deformation of transparent acrylic plastic crew inclosures on aircraft parked exposed to the sun, it is recommended that the following precautions be observed:

(a) When surrounding air temperature is below 100°F. (38°C.), no special precautions are necessary except that when covers are used, no part of the cover shall come in contact with the transparent acrylic plastic.

(b) When surrounding air temperature is between 100° and 120°F. (38° and 49°C.), inclosures should be opened sufficiently to permit free circulation of air through the aircraft and under the inclosure. If a canopy cover is needed to protect the transparent inclosure from wind-blown sand or grit, the cover shall not come in contact with the transparent plastic surfaces.

(c) When surrounding air temperature is above 120°F. (49°C.), the inclosure must be opened and protected from the sun by a suitable cover which does not come in contact with the transparent acrylic plastic. If possible, the aircraft should be parked in the shade.

Caution: When removing inclosure covers, lift off, as sliding may cause abrasion of the acrylic plastic surface.

230. Installation of Transparent Acrylic Plastic Panels

There are a number of methods for installing transparent acrylic plastic panels in aircraft. Which method the aircraft manufacturer uses depends on the position of the panel on the aircraft, the stresses to which it will be subjected, and a number of other factors. When installing a replacement panel, follow the same mounting method used by the manufacturer of the aircraft.

a. *General Installation Information.* When difficulty is encountered in rivet installation, bolts may be substituted when installing replacement panels, providing the manufacturer's original strength requirements are met and the bolts do not interfere with adjoining equipment.

(1) In some instances, replacement panels do not fit the installation exactly. When adjustment of a replacement panel is necessary, the original design drawing, if available, should be consulted for proper clearances.

(2) Fitting and handling should be done with masking material in place. Do not scribe plastic through masking material. On edges where transparent materials will be covered or used for attachment, remove masking material. When subject to large stresses, transparent acrylic plastics are apt to craze. It is of prime importance that acrylic plastics be mounted and installed so that such stresses are avoided.

(3) Transparent acrylic plastic is brittle at low temperatures; therefore extra care must be exercised to prevent cracking in the course of maintenance operations. Installation of transparent acrylic plastic parts should be done at normal temperatures if practical.

(4) Never force a transparent acrylic plastic panel out of shape to make it fit a frame. If a replacement does not fit easily into the mounting, obtain a new replacement or sand panel sufficiently to obtain exact size that conforms with mounting frame.

(5) Do not heat and reform areas of the panel, as local heating methods are likely to be only superficial and not thorough enough to reduce stress concentrations.

(6) Transparent acrylic plastics expand and contract approximately three times as much as metal; therefore, suitable allowance for dimensional changes with temperature must be made. Use the values given in table 76 as minimum clearances between the frames and the acrylic plastics.

Table 76. Expansion and Contraction Allowances

Dimension of panel (in.) **	Dimensional allowance (in.) ***	
	Required for expansion from 77° F. (25° C.) to 158° F. (70° C.)	Required for contraction from 77° F. (25° C.) to -67° F. (-55° C.)
12	0.031	0.050
24	0.062	0.100
36	0.093	0.150
48	0.124	0.200
60	0.155	0.250
72	0.186	0.300

* Where the configuration of a curved part is such as to take up dimensional changes by change of contour, the allowances given may be reduced if it will not result in localized stress.

** For dimensions other than those given, use proportional clearance.

*** Installations permitting linear change at both ends require one-half the listed clearances.

b. *Bolt and Rivet Mountings.* Bolt and rivet installations which go through the transparent acrylic plastic will not be used on pressurized aircraft. When special considerations on unpressurized aircraft make channel and clamp mountings impractical, holes may be drilled in the plastic for bolt and rivet installations. These installations are adequate, but should be used only when other methods cannot be used. Because of difficulties experienced with rivet installations, bolt mountings are preferable.

(1) In bolt installations, spacers, collars, shoulders, or stop nuts should be used to prevent excessive tightening of the bolt (fig. 357). When such devices are used by the aircraft manu-

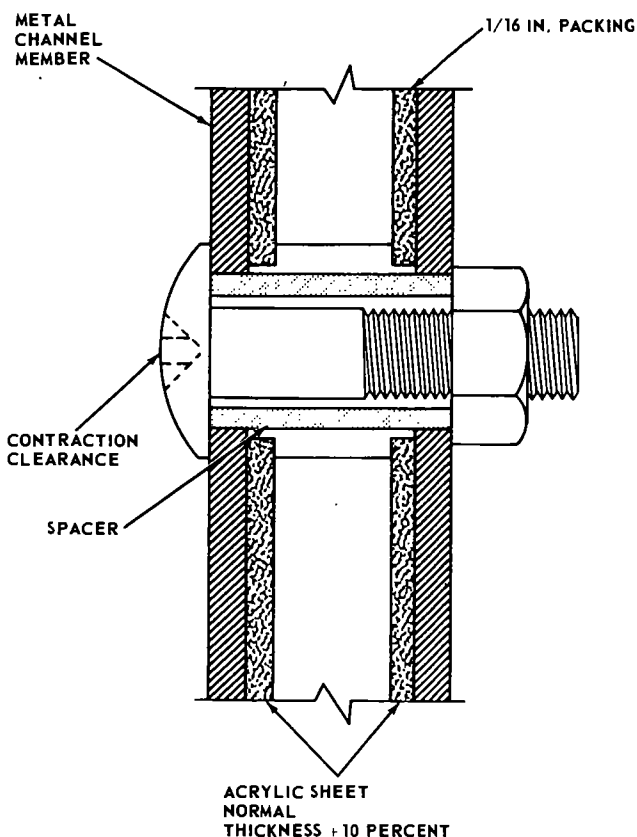


Figure 357. Bolt and spacer installation.

facturer, they should be retained in the replacement installations.

(2) To insure long service, special consideration should be given the following factors.

(a) Use as many bolts or rivets as practical.

(b) Distribute total stresses as equally as possible along the bolts and rivets.

(c) Make sure holes drilled in the plastic are sufficiently larger than diameter of the bolt to permit expansion and contraction of the plastic relative to the frame.

(d) Make sure holes in plastic are concentric with holes in frame so that the greater relative expansion of the plastic will not cause binding at one edge of the hole.

(e) Use oversize tube spacers, shoulder bolts, rivets, capnuts, or some other device to protect the plastic from direct pressure.

(3) It is important that the holes drilled in acrylic plastic sheets be smooth and completely free from any nicks or roughness.

c. *Synthetic Fiber Edge Attachment.* Modern edge attachments to transparent acrylic plastic assemblies are made of synthetic fibers specially impregnated with plastic resins. The most

commonly used fibers are glass, orlon, nylon, and dacron.

(1) *Laminated edge attachments.* Reinforced laminated edge attachments are the preferred type, especially when mounting by bolts or rivets is necessary. The edges have the advantage of more efficiently distributing the load and reducing failures caused by differential thermal expansion.

(a) Laminated edge attachments (fig. 358 can be mounted by any of the fore-

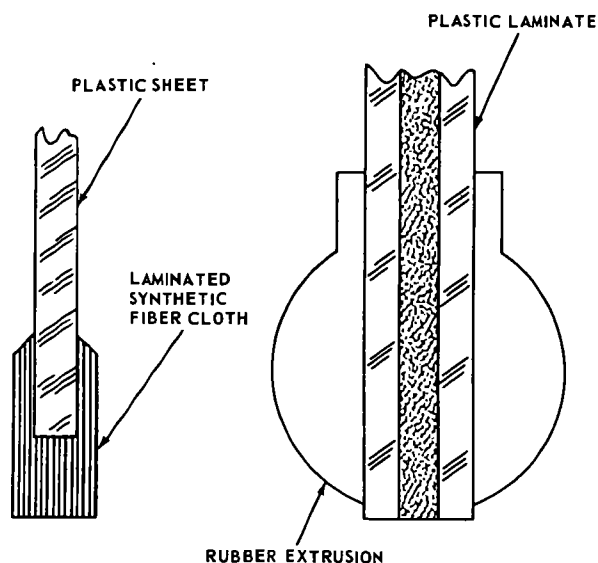


Figure 358. Typical laminated edge attachment.

going methods, with any needed holes drilled through the edge attachment material and not the transparent plastic.

(b) The most efficient method of mount-

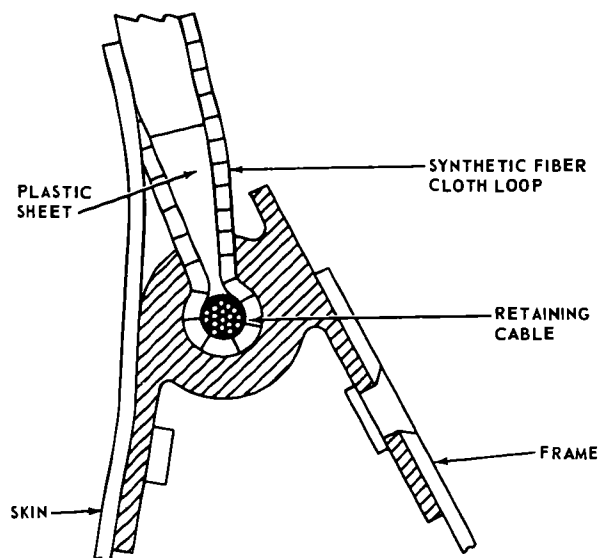


Figure 359. Typical loop edge attachment.

ing a laminated edge attachment is by the slotted-hole method. The slotted holes are in the edge, attachment and allow for differential thermal expansion.

(2) *Loop attachments.* Fabric loop attach-

ments are attached to the acrylic plastic material with a cable or extrusion contained within the loop. A special extrusion is necessary to contain the loop and cable. A typical loop installation is shown in figure 359.

Section IV. TRANSPARENT CELLULOSE ACETATE BASE THERMOPLASTICS

231. General

The methods used for fabrication, repair, and maintenance of cellulose acetate base plastics are similar to those used for regular acrylic plastic, Military Specification MIL-P-6886, and heat-resistant acrylic plastic, Military Specification MIL-P-5425.

232. Working Practices

In working with and handling cellulose acetate base plastics, give attention to the following variations and additions to the recommendations already given for regular acrylic plastic, Military Specification MIL-P-6886, and heat-resistant acrylic plastic, Military Specification MIL-P-5425.

a. Since the chemical composition of cellulose acetate base plastics differs greatly from that of acrylic plastics, the adhesive used is of a different type. Generally two types are used, solvent and dope.

(1) *Solvent-type adhesive.* Solvent-type adhesive is generally used where transparency must be maintained in the joint. It is relatively quick-drying and is well adapted for use in making emergency repairs. However, even though the adhesive is quick-drying, the drying time will vary with the size of the joint and atmospheric conditions. Acetone may be used as a solvent-type adhesive.

(2) *Dope-type adhesive.* Dope-type adhesive is preferred for use where the surfaces to be joined do not conform exactly. This adhesive softens the surfaces of the joint and, at the same time, creates a layer between the two pieces being cemented. However, it does not give a transparent joint and is slower drying than the solvent adhesive. It will take from 12 to 24 hours for the joint to reach full strength.

b. Cold, dry cellulose acetate base plastic sheets have a tendency to chip during machining; therefore, they should be conditioned for a period of about 24 hours at a temperature ranging

from 80° to 90°F. (27° to 32°C.). If water is used as a lubricant during machining, use it sparingly, as cellulose acetate base plastics absorb moisture more readily than acrylics.

c. When cutting cellulose acetate base plastics, an automatic metal shearing device may be used. For thin sheets, use regular handtype tin shears. Cutting should be performed only after the plastic sheet has been conditioned as described in b above.

d. Cellulose acetate base plastics may be formed cold if the curvature is of a simple nature and has a radius not smaller than 70 times the sheet thickness.

e. Do not cold-form cellulose acetate base plastic sheets below a temperature of 80°F. (27°C.). For hot-forming, the correct temperature ranges from 250° to 280°F. (121° to 138°C.). Heating time ranges from 4 to 12 minutes for plastic sheets 3/32 inch to 1/4 inch thick. If heated to a temperature higher than 280°F. (138°C.), small parallel sheeter lines will appear on the surface of the plastic sheet and impair its optical qualities. Be very careful when forming heated cellulose acetate base plastics, as forming temperatures are much more critical for these plastics than for acrylic plastics. Cellulose acetate base plastics may be heated in hot air ducts or by blowing warm air onto the sheet while it is being formed.

f. The expansion and contraction rates of cellulose acetate base plastics are greater than those of acrylic plastics, so make greater allowances when mounting them. These plastics are affected by moisture and will swell as they absorb water. In general, allow 1/8 inch per foot of panel length for expansion, and 3/16 inch per foot for contraction.

g. It is sometimes possible to clear a badly scratched surface of cellulose acetate base plastic by applying a coating of clear varnish. When polishing and buffing, follow the same procedure as employed for acrylic plastics, except operate the buffing wheel at 1450 rpm.

Section V. THERMOSETTING PLASTICS (REINFORCED FIBERGLASS)

233. General

Reinforced fiberglass parts consist of layers of

glass cloth which have been impregnated with chemical resins, molded to a particular contour,

and cured to a hard consistency. Once formed, they will retain that shape until they become useless because of deterioration, damage, careless handling, etc. These parts can develop high physical strength, sometimes greater than 80,000 psi in flexure. In addition to having high physical strength, reinforced fiberglass parts are light in weight and resistant to water, weather, aging, and a variety of chemicals. Because of this combination of characteristics, reinforced fiberglass is widely used in interior furnishings, electrical and radio equipment, control surfaces, and ducting.

234. Types of Resins

The three principal thermosetting resins used on aircraft are polyester resins, epoxy resins, and phenolic resins.

a. Polyester Resins. Polyester resins are manufactured from a combination of organic acids and alcohols. When they are mixed with a catalyst, according to manufacturers instructions, and cured by heat or at room temperature, they gradually change from syrupy liquids to hard solids.

(1) Curing reaction is controlled by the type of catalyst that is added to the resin. Certain catalysts can produce a hardening reaction in 15 seconds, while other catalysts require as long as 30 days. In most aircraft applications, the recommended mixture will cure under infrared heat in several hours. Because pot life is limited, only the amount of resin necessary for each application should be prepared. The surrounding temperature is also taken into consideration when resin is mixed.

(2) Polyester resins are easily applied to any surface and they impregnate glass fiber cloth quickly and thoroughly because they are liquid in the uncured state. In addition, their mechanical, electrical, and weathering characteristics are good, and they can be colored to provide a wide variety of appearances.

(3) Polyester resins are used in the construction of radome and radio antenna shields, and they are used on control surfaces because of their strength, resistance to weather, and ease of application.

b. Epoxy Resins. Epoxy resins are similar to polyester resins in that they are liquid in the uncured state and they are cured with curing agents or hardeners. Epoxy resins have good mechanical strength and wearability when combined with suitable reinforcements, such as glass cloth. They are excellent fiberglass-to-metal and fiberglass-to-fiberglass adhesives. The dielectric properties of these resins are not quite as good as those of the polyester resins; therefore,

the use of epoxy resins in radomes and in radio antenna guards is minimized at the present time. Resin manufacturers are overcoming this deficiency, however, and it is anticipated that future aircraft will have many more epoxy components.

c. Phenolic Resins. Phenolic resins are manufactured from a combination of phenols and aldehydes or phenols and formaldehyde. Phenolic resins are similar to polyester and epoxy resins in many respects, but, unlike the other resins, phenolic resins are usually heat-cured in three separate stages. These stages are designated as A, B, and C. During the A stage, prior to heating, the phenolic resin is both fusible and soluble. The phenolic resin advances to the B stage when the specified amount of heat is applied where it becomes a fusible solid of only limited solubility. Further application of heat advances the phenolic resin to the C stage, where it becomes hard, strong, insoluble, and infusible.

(1) Phenolic resins cannot be poured directly into a mold because phenolic resins, even when they are in the A stage, are not fully reactive liquids as are polyester and epoxy resins. They must first be applied to the cloth reinforcement and advanced, by heat, to the B stage in order to be used.

(2) Fabric-reinforced phenolic laminates are fabricated in the A stage, using low-pressure procedures similar to those used in the production of polyester laminates. Preimpregnated, post-formable, laminated phenolic sheet stock may also be purchased from plastic manufacturers in sheets of phenolic-impregnated fabric that has been cured to a stage between A and B, or in some cases between stages B and C. Blanks are cut from the sheet and heat-formed between matched dies. The heat used for the forming operation advances the laminate to stage C.

235. Types and Grades of Glass Cloth

The function of glass cloth in glass cloth reinforced parts is no less important than the function of the resin itself in providing high compressive and tensile strength. Many properties of glass cloth are similar to those of ordinary glass. These are high electrical resistance, chemical inertness, low specific gravity, and moderate thermal conductivity. The most important difference between ordinary glass and glass cloth is strength. Ordinary glass can withstand only a small amount of stress, but glass cloth filaments have a tensile strength of approximately 400,000 psi.

a. Glass cloth is manufactured by twisting glass filaments into strands, the strands into threads, and the threads into yarns. In weav-

ing a glass cloth fabric, the yarn is lengthwise in a loom (warp yarn) and interlaced by woof or fill yarns. The number of warp and fill yarns used, the weave design, and the construction of the yarn determine the strength of glass cloth fabric in a laminate.

b. One type of glass cloth weave that is frequently used in construction of aircraft parts in No. 181, an eight-harness satin. This type weave has a balanced construction; that is, the same yarns in almost equal amounts run in warp and fill directions. This gives the glass cloth equal strength in either direction. This type of weave provides a smooth surface finish in completed parts.

236. Classes of Repair

For convenience in presentation and for clarity in designating repair procedures to be used, damages to sandwich-type laminate material parts are divided into groups or classes according to severity and possible effect upon the aircraft structure. The following classes are used in presentation of repair techniques.

a. *Class I Repair.* This type of repair includes scars, scratches, surface abrasions, or minor rain erosion affecting the outer facing only (fig. 360).

b. *Class II Repair.* This type of repair includes punctures, delaminations, contaminates, or fractures in one facing only, possibly accompanied by damage to the core, but without damage to opposite facing (fig. 361).

c. *Class III Repair.* This type of repair includes damage extending completely through the sandwich-type laminate material, affecting both the facings and the core (fig. 362).

237. Repair Procedures for Sandwich-Type Laminate Material

Sandwich-type laminate material is that material which is constructed of a center core of the desired material and laminations of fiber-

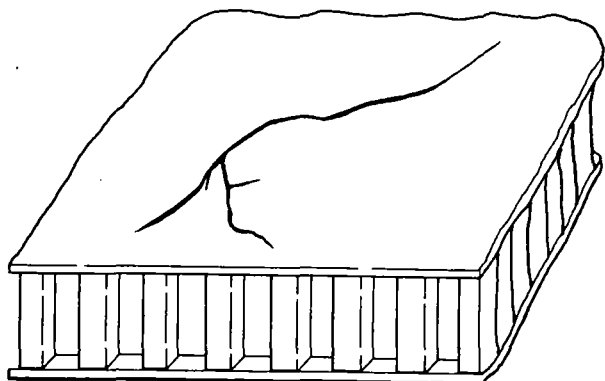


Figure 360. Class I damage to the face.

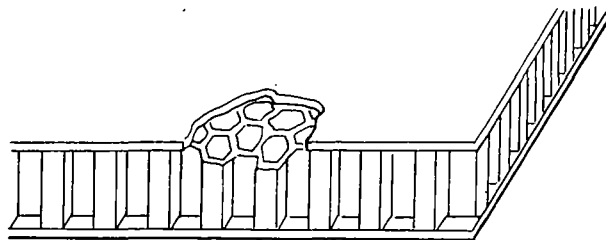


Figure 361. Class II damage to face and core.

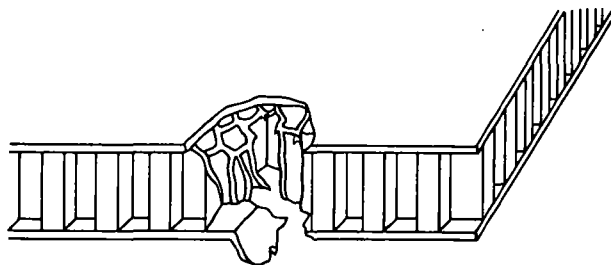


Figure 362. Class III damage to both facings and core.

glass cloth on each outer side of the core. The type of core used is determined by the requirements of the part being constructed. The following are repairs which may be accomplished on sandwich-type laminate material.

a. *Class I Repair.* Scars, scratches, surface abrasions, or minor rain erosion not penetrating through the outer facing shall be repaired as follows:

(1) Clean damaged area thoroughly and carefully, using a clean cloth saturated with methyl-ethyl-ketone, Federal Specification TT-M-261, or other approved cleaning agent.

(2) Lightly sand damaged area, using No. 280 grit sandpaper. Clean sanded surface thoroughly, using methyl-ethyl-ketone, Federal Specification TT-M-261. Moisture and solvents should be completely removed to prevent their inhibiting the cure of the resin.

(3) Apply one or two coats (depending upon severity of abrasion) of applicable catalyzed resin to abraded surfaces.

(4) Over this coated surface, apply a sheet of colored cellophane, Federal Specification L-C-110, or polyvinyl alcohol (PVA) film extending 2 or 3 inches beyond surface. Cellophane or PVA film prevents exposure to air and will provide a smooth surface for curing resin.

(5) Tape cellophane or PVA film in place and work out all air bubbles and excessive resin with the hand or a rubber squeegee. Subject resin-coated surface to curing temperatures as specified by the resin manufacturer's instruction sheet.

(6) After resin has cured or set, remove cellophane from cured resin and remove any excessive resin by sanding.

Note. If rain erosion coating was removed or adversely affected by accomplishing the repair, it will be replaced in accordance with instructions in the applicable manual.

b. Class II Repair. Damages extending through two plies of the laminated fiberglass facing, or completely through one facing and possibly into the core, will require removal of that portion of damaged facing and core and replacement with approved materials so that normal stress can be carried over the area. The preferred method of removing damaged face plies in accomplishing a class II repair is by the step joint method. For small damages, the scarf method of repair may be used.

(1) *Step joint method.* The following are procedures for performing a step joint repair on a piece of sandwich-type laminate material.

(a) Ascertain extent of damaged area by inspection prior to beginning repair. Damaged portion may be identified by the dissimilar appearance to that of surrounding portion by using a light source or, when tapped lightly with a blunt instrument, damaged area will have a dull or dead sound whereas an uninjured area will have a clear, metallic sound. Coating should be removed prior to inspection for defects.

(b) With the aid of a straightedge or compass, outline damaged area by scribing a rectangle or square with rounded corners, or a circle that will necessitate removal of a minimum of sound material. Extend sides of rectangle, square, or circle a distance in inches equal to number of plies to be removed less 1 inch (5 inches if six plies are to be removed, 4 inches if five plies are to be removed, etc.). Overlap should be at least 1 inch per ply of glass cloth. In case of core damage, allow a minimum of 1/2 inch between edge of innermost ply and periphery of core material that is to be removed. Rain erosion or other coating will be removed from an area larger than cutout area by 2 inches on all sides.

(c) With aid of a straightedge, use a sharp knife or other specially prepared cutter and cut along lines scribed in outermost ply (fig. 363). Use extreme care not to cut or score underlying ply. A suggested method is to cut through overlaying ply in a series of cuts rather than attempt to cut through ply in one cut.

Caution: If layer of glass cloth underneath is cut or scratched, the strength of repair will be lessened.

(d) Remove cut outermost ply by inserting a knife blade under one corner and prying loose carefully. When this outermost ply is removed, scribe on next exposed ply a similar out-

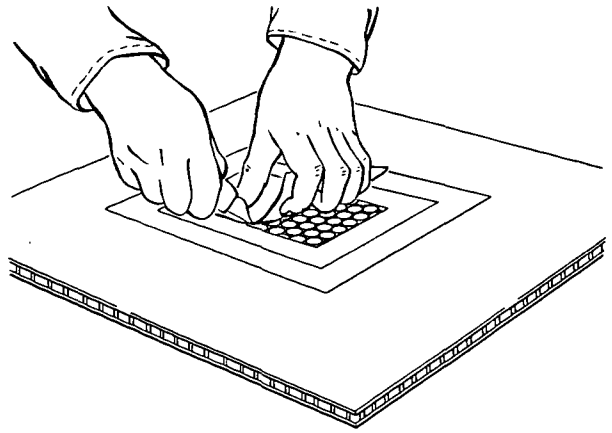


Figure 363. Removing damaged face plies using step joint method.

line, except reduce dimensions 1 inch in all directions. (Overlaps will be 1 inch each ply.) Repeat this procedure until all damaged plies have been removed.

(e) Lightly sand exposed plies and clean surfaces using methyl-ethyl-ketone, Federal Specification TT-M-261. Allow to dry thoroughly before completing repair buildup.

Note. Do not use methyl-ethyl-ketone on sandwich-type laminate materials with core material conforming to Military Specification MIL-C-8087 (foam core). Clean surface with dry, lint-free cloth only.

Warning: The sanding operation on glass cloth reinforced laminates gives off a fine dust that may cause skin irritations. Breathing of an excessive amount of this dust may be injurious; therefore, precaution as to skin and respiration protection will be observed.

(f) A convenient means of preparing glass cloth patches is to impregnate cloth patches with applicable catalyzed resin and insert individual patch ply between two sheets of colored cellophane, Federal Specification L-C-110, larger than patch by at least 2 inches on all sides. Impregnated glass cloth will contain 45 to 50 percent of applicable resin after cellophane has been removed. (Weight of resin equal to weight of dry glass cloth comprises 50 percent resin content.) Patches are then cut to desired size and shape without usual fraying of edges. Replacement or layup of a bond ply patch (ply adjacent to core) may be either butted to existing bond ply or overlapped as shown in figure 364. All other replacement patches will be butted to existing plies as shown in figure 365.

(g) When repaired laminate has cured, lightly sand if necessary to obtain smoothness or to remove excess cured resin and/or to prepare surface for required coating. A properly cured laminate will have a minimum average Barcol hardness of 55 when a Barcol impressor is em-

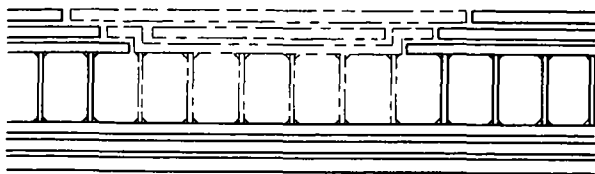


Figure 364. Replacing plies and core using step joint method.

ployed perpendicular to surface of laminate. An average derived from ten readings is considered satisfactory for large parts; five readings for small parts should be sufficient.

Figure 365. Replacing face plies, using step joint method.

Note. Do not take Barcol readings on surface where skin is less than 0.01 inch thick. When testing honeycomb sandwich-type laminated structures, the impressor's point should be placed over supporting cell wall to obtain truer readings and also to avoid damage to face ply. Low readings may be noticed if point is placed over open cell due to flexing of face ply.

(h) In case of damage to honeycomb core, repeat procedures outlined for removal of damaged face plies in (b) through (d) above. Also cut out damaged core and lightly sand exposed surface of inner ply of cloth. If core replacement exceeds 4 inches square, inner ply will be replaced and core placed in position on newly installed wet bond ply. Removal of inner bond ply will be accomplished by standard procedures. Removal of bond ply adjacent to good core material may be difficult, as existing core will prevent proper positioning of cutting knife. For this reason, boundary of inner ply cutout may extend approximately 1 inch inside boundary of good core area. When new bond ply is installed, surrounding old bond ply must be coated with prepared resin mix prior to placement of new core material. Core replacement of an area less than 4 inches square may be accomplished without replacing inner bond ply. After thoroughly cleaning with methyl-ethyl-ketone, Federal Specification TT-M-261, cut a piece of core material to exact size of damaged area. Thickness and cell size of core material shall be as specified by manufacturer's drawings. If slicing of honeycomb core is required, a band saw is most convenient to use. Blade should have approximately 32 teeth per inch and a speed of approximately 5,000 feet per minute.

(i) After area is thoroughly clean and dry, apply one coat of applicable resin to area cut out and a like amount on all mating surfaces of replacement core. Insert core material, insuring it conforms closely to existing undamaged honeycomb core. On large curved repairs, core will be cut into pieces small enough to conform

to curvature or preformed to obtain proper fit and maintain desired contour. Insert first impregnated ply over core material and apply light and uniform pressure by means of tape, sand, or vacuum bags. Prevent excess resin from entering core cells, as this may hinder efficiency of the part. Cure repair area, using heat lamps or by inserting entire part in air-circulating oven at temperatures in accordance with resin manufacturer's instructions.

(j) After cure is completed, complete face ply buildup by repeating procedures outlined in (f) and (g) above. Make all repairs to honeycomb core from inside of part if possible.

(2) *Scarf method.* The following are procedures for performing a repair on a piece of sandwich-type laminate material using the scarf method.

(a) The scarf method may be used when repair of damage will require removal of an area less than 3 inches in diameter. The scarf method of removing plies from thin-face foam core parts is not recommended if damage extends into the core.

(b) The scarf method consists of sanding out the damaged face plies to a circular or oval disk shape (fig. 366).

Caution: Avoid damage to opposite facing or delamination between bond ply and core.

(c) Scarf back damaged plies carefully to a distance of at least 50 times the total face ply thickness by using sander, Federal Stock No. 5130-537-3394, or by hand-sanding using No. 180 grit sandpaper. Performing the scarfing operation accurately enough to provide a uniform taper and obtain acceptable scarfs usually requires practice.

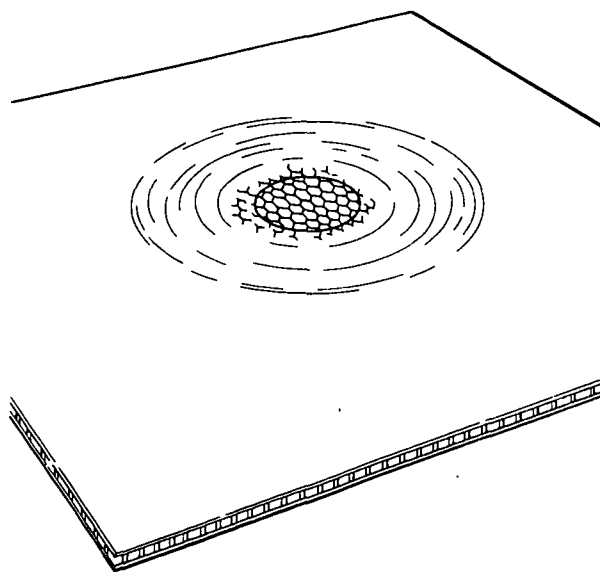


Figure 366. Damaged face plies removed, using scarf method.

(d) Prepare glass cloth laminations for facing repairs by cutting largest piece to exact outside shape of scarfed area. Cut smallest piece so that it overlaps scarfed area by its proportionate amount, depending upon number of plies in repair. Cut intermediate pieces so as to have equal taper.

(e) Prepare patches in accordance with (1)(f) above, and install in accordance with the following instructions.

1. Impregnate glass cloth patches with 45 to 50 percent of applicable resin. (fig. 367). (Weight of resin equal to weight of dry glass cloth constitutes a 50 percent ratio.)

2. When all patches are ready for assembly, coat sanded surfaces with one brush coat of applicable resin.

3. Fit impregnated glass cloth patch ply in smallest cutout section. With approximately 1/2-inch overlap, fit next larger impregnated cloth repair ply in like manner. Complete repair buildup and cure as previously outlined for step joint method in (1) above. See figure 368 for typical scarf method, class II repair.

c. *Class III repair.* Damages completely through the sandwich-type laminate material will be repaired by removing and replacing the damaged face plies and core material as previously outlined for class II repair. Never remove inner and outer face ply at the same time. One facing will be completed before repair is made on the opposite facing.

(1) To accomplish class III repair, it is necessary that opposite side of sandwich-type laminate material be provided with a temporary mold or block to hold core in place during first face ply buildup. The mold is provided with a shim simulating thickness of opposite facings

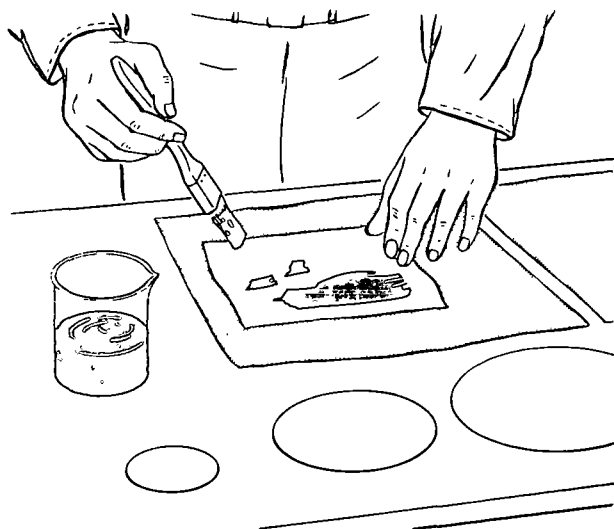


Figure 367. Suggested method of resin-impregnating replacement plies.

and is secured in place by means of clamping, propping, or lashing preparatory to core replacement and face ply buildup. Replacement core is coated with applicable catalyzed resin on all edges and top surface only, leaving bottom surface (next to shim) uncoated.

Note. Foam core edges will not require resin coatings.

(2) Remove and replace damaged facings as previously outlined for class II repair in b above.

(3) Repeat repair procedures on opposite facing, except cutout ply area will be larger by approximately 2 inches than first ply cutout area on opposite face repair. This will prevent joints of inner and outer repair area from being in same position (fig. 369).

(4) Sanding of any type repair to obtain desired contour or for purpose of removing wrinkles is not permissible if this sanding extends into the glass fabric. The contour of the part will be retained throughout the repair by use of molds.

d. *Class II and Class III Repair to Plastic With Foamed-In-Place Core.*

(1) In case of damage to the foam core, repeat procedures outlined in b and c above for removal and repair of damaged face plies.

(2) Removed damaged foam area by cutting vertically to surface of face laminate.

(3) Scrape inner skin surface clean, avoiding grease or oil film in area to insure good bondage of foam to face laminate.

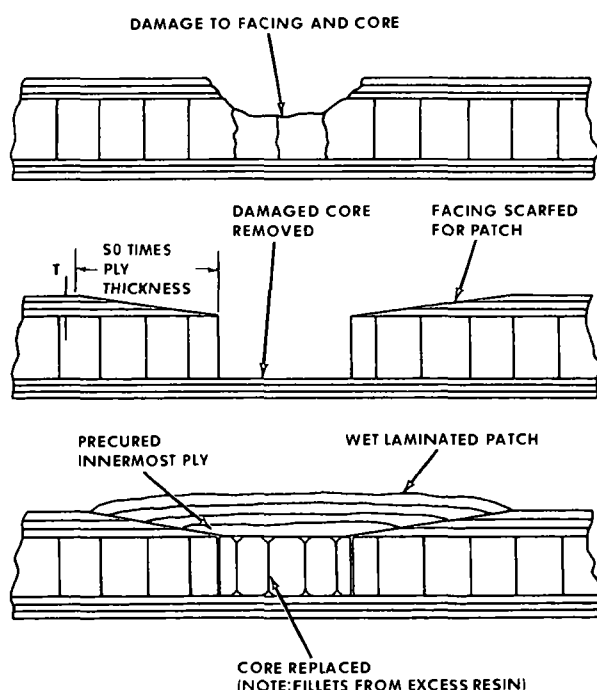


Figure 368. Typical scarf method for class II repair.

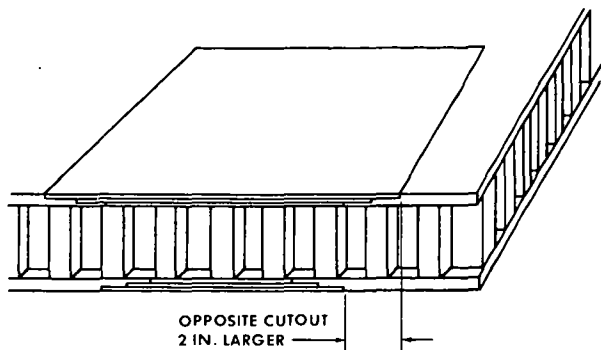


Figure 369. Completed double face patch repair.

Caution: Do not use Acetone, Federal Specification O-A-51, or Toluene, Federal Specification TT-T-548, as a solvent cleaner, as it will soften and weaken the foam core surrounding the cut-out area.

(4) A precise and cured alkyd di-isocyanate foam plug of matching density and thickness to existing core may be cut to fit precisely in area of core hole without bonding resin on sides. An alternate method is to mix alkyd di-isocyanate according to manufacturer's directions and pour into cavity to fill one-fourth of hole height.

(5) Clamp backup plate overlapping patched area by 4 inches and with 1/4-inch hole over cavity. Backup plate should be cut from metal capable of being constructed to conform to curvature of part surface. Backup plate should have a lubricant such as bentene, DCXE-135A, or equivalent, on face next to cavity to avoid adhesion of foam to plate.

(6) Using infrared lamps, start with 110°F. (43°C.) until full expansion and gelation occurs, then increase temperature to 260°F. (127°C.) for 2 hours. Drop temperature to 100°F. (38°C.) before removing backup plate.

(7) Remove excess foam parallel to core level by sanding.

e. Class II and Class III Repair to Plastic With Fluted Core.

(1) For damage extending into or through the deicing flutes, remove plies as outlined in b(1)(a) through (e) above.

(2) Remove damaged flutes by carefully cutting vertically down to opposite face ply.

(3) Carefully remove damaged flutes and exposed inner ply in accordance with b(1)(g) above. Preform replacement fluted core on a section of a mold conforming to curvature of area to be replaced. Flute dimension shall be as specified by the manufacturer's drawings.

(4) Fabricate replacement sections of fluted core in accordance with processes used in manufacture of the part.

(5) Cut a piece of preformed core from appropriate area and trim to exact size of prepared repair area.

(6) Replace inner ply and fluted core in accordance with the procedures outlined in b(2)(d) above.

(7) After fluted core material is replaced, complete repair face ply buildup in accordance with procedures outlined in b(1)(f) and (g) above.

238. Repair Procedures for Solid Laminate Material

Nonstructural parts, such as junction boxes, heater ducts, relay shields, and other electrical components are manufactured from mat-molded fiberglass. The assemblies are fabricated by a process wherein the chopped fibers are molded around a form, bonded together by use of a resin, and cured while under heat and pressure.

a. Types of Damage. Carelessness in removing or handling mat-molded parts may cause the assembly to become damaged. Vibration may be another factor in the causing of cracks in the assemblies. Damage to mat-molded parts usually consists of a hole or crack in the assembly (fig. 370). Similar repair procedures will be used for either type of damage.

b. Repair Procedures. The following procedures are typical procedures that may be used in the repair of a mat molded assembly. They are not to be construed as the only procedures that may be used.

(1) Inspect damaged part and determine extent of damage. Remove paint or protective coating from around damaged area.

(2) Stop-drill the end of crack. Size of drill should not be smaller than 1/8 inch and not larger than 3/16 inch.

(3) Lay out and sand damaged area to dimensions given in figure 371.

(a) Remove one-third total thickness of material from both sides of damaged area.

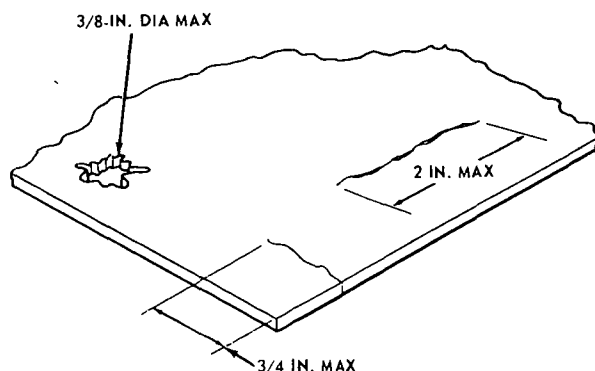


Figure 370. Typical damage to mat-molded parts.

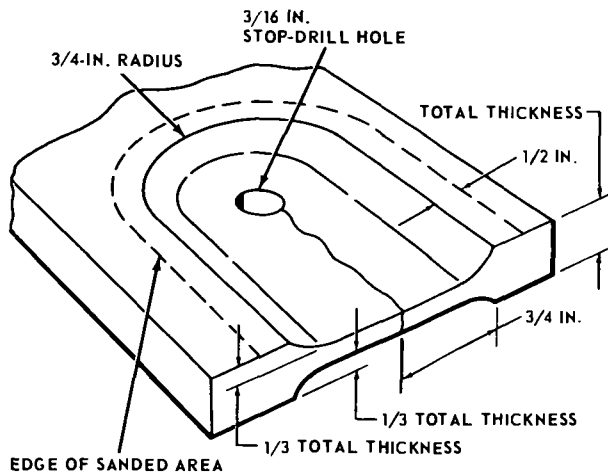


Figure 371. Mat-molded repair.

(b) Bevel area 15° to 45° as shown in figure 364.

(c) Sand $1/2$ inch beyond beveled area.

(4) Prepare two pieces of PVA film and two pieces of metal large enough to cover repair area.

(5) Check and start air-circulating oven (fig. 341). Set temperature regulator at 220°F . (104°C).

(6) Select and prepare resin mixture in accordance with resin manufacturer's instructions.

(7) Cut and saturate mat fiberglass material in prepared resin. Cut and saturate enough pieces of material to build up beveled-out area to its original contour.

(8) Insert saturated mat fiberglass material into repair area (fig. 372).

(a) Repair one side at a time.

(b) Cover each side with precut PVA film after impregnated mat fiberglass material has been installed.

(c) Place prepared metal plate on each side of repair after PVA film is installed. Secure metal plates in place using C-clamps.

(9) Place assembly in preheated oven and leave for period of time specified by resin manufacturer's instructions.

(10) Remove assembly from oven and let it cool at room temperature. After cooling, remove C-clamps, metal plates, and PVA film.

(11) Sand both sides smoothly and to original contour of part.

(12) Inspect repair for soundness by tapping lightly with a coin or light aluminum hammer. A good repair should resound with a metallic ring.

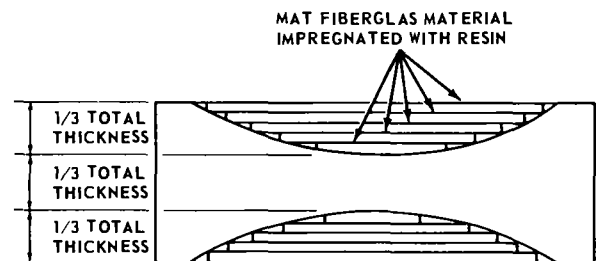


Figure 372. Insertion of precut, saturated fiberglass material.

APPENDIX A

REFERENCES

1. Army Regulations

AR 320-50

AR 755-1

Authorized Abbreviations and Brevity Codes
Reporting, Utilization, and Redistribution of
Installation US Army Materiel Command,
and Oversea Command Excess Personal
Property

2. Department of Army Pamphlets

DA Pam 310-series

Military Publications Indexes

3. Military Standards

MIL-STD-455

Alloy Designation System for Wrought Cop-
per and Copper Alloys

4. Technical Manuals

TM 55-1500-series

General Aircraft and Aircraft Component
Maintenance

TM 55-1510-series

Operator's, Organizational, DS and GS Main-
tenance Manuals (Fixed-Wing Aircraft)

TM 66-1520-series

Operator's, Organizational, DS and GS Main-
tenance Manuals (Rotary-Wing Aircraft)

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